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Beyond technology-push and demand-pull: Lessons from California's solar policy

Margaret Taylor *

Richard and Rhoda Goldman School of Public Policy, University of California, Berkeley, 2607 Hearst Avenue, Berkeley, CA 94720-7320, USA

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ABSTRACT

The scale of the technological transformation required to reduce greenhouse gas emissions to "safe" levels while minimizing economic impacts necessitates an emphasis on designing climate policy to foster, or at least not impede, environmental innovation. There is only a weak empirical base for policy-makers to stand on regarding the comparative innovation effects of various climate policy options, however. Empirical scholarship in environmental innovation is hindered by the complexity of both the innovation process and the interactions between the dual market failures of pollution and innovation that are in play, and it appears that the field would benefit from the structure provided by a common lexicon. This paper focuses on the issues related to policy categorization in this field; these issues have received little attention in the literature despite their importance to making insights gained from empirical studies generalizable. The paper reviews the origins, strengths, and weaknesses of the dominant policy typology of technology-push versus demand-pull instruments. Its primary contribution, however, is to assemble a comprehensive chronology of solar policy in California and its impacts on innovation, where known, and then use this as a basis for building a new policy categorization that takes advantage of the intuitive resonance of the dominant typology, while encompassing the broader range of policy instruments that are employed in practice in order to stimulate environmental innovation. The most noteworthy aspect of the new categorization is that it introduces a third category of environmental innovation policy instrument that focuses on improving the interface between technology suppliers and users. This reflects developments in the economics of innovation literature as well as considerable evidence in the domain of distributed solar energy technologies that opportunism by some of the actors that work at this interface can be a barrier to innovation.

* Tel.: +1 11 510 642 1048; fax: +1 11 510 643 9657.
E-mail address: mataylor@berkeley.edu.

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1. Introduction

Analysts generally agree that considerable technological innovation will be necessary to reduce greenhouse gas emissions to "safe" levels while minimizing economic impacts. Market failures related to both environmental pollution and innovation decrease the likelihood that Adam Smith's "invisible hand" will provide that innovation (Jaffe et al., 2005). A critical question, therefore, is which policy approaches will best serve to foster climate-relevant innovation, given scientific uncertainties about the definition and timing of safety.

Scholarship in environmental innovation does not provide easy answers, in part because there is a weak empirical basis for policy design recommendations due to a lack of systematic, retrospective policy evaluation. But even with more than thirty years of renewable energy, energy efficiency, and environmental policy experience to draw on, such evaluation is difficult to accomplish, for a number of reasons. At the broadest level, the complexity of the interaction amongst the relevant market failures complicates evaluation, as does the multi-faceted innovation process itself, which is defined differently by different authors (see, for example, Grubler et al., 1999; Jaffe et al., 2005; Taylor et al., 2005a). In addition, the dependent variable of "innovation" is difficult to define, and is usually replaced, by necessity, with imperfect proxy metrics (several of these metrics, and their imperfections, are detailed in Gallagher et al., 2006 and Taylor, 2001).

A particularly policy-relevant weakness in the environmental innovation literature, however, has received little attention to date. That weakness lies in the way the independent variables related to policy are defined. Although most empirical studies focus on policy instruments that are tailored to a specific set of circumstances, the attempt to draw more generalizable conclusions from those studies has required a typology of government actions. The dominant typology splits environmental policy instruments with relevance to innovation into two camps: "technology-push" instruments, which influence the supply of new knowledge, and "demand-pull" instruments, which affect the size of the market for a new technology. This dichotomy has gained currency in recent years, both in academia (e.g., Jaffe et al., 2005; Margolis, 2002; Norberg-Bohm, 2000; Sawin, 2001; and Taylor et al., 2005b) as well as in professional policy circles. In January 2006, for example, the California Public Utilities Commission (CPUC) used this terminology in an interim decision regarding a new solar energy incentive program. In the CPUC's language, solar energy technologies should be supported with "a 'push' from an incentive program" and a "'pull' [from] a program design that encourages technological improvements."

The irony of the technology-push/demand-pull typology is that while it is novel to environmental policy research, it is an adaptation of a somewhat outdated thread from the economics of innovation literature. The classic research thread contrasted the influence on the rate and direction of technological change of advances in scientific and technical understanding (also referred to as "technological opportunity") versus the "calling forth" of innovations in response to changes in market demand (or to meet "user needs") (see Mowery and Rosenberg, 1979). It was particularly relevant to the highly influential vision for post-World War II U.S. technology policy articulated in Bush (1945), which saw the innovation process as a linear progression from basic science to applied research to product development to commercialization. But later research moved beyond the linear model and focused instead on the importance to successful innovations of an iterative innovation process that involves interactions between supply and demand, such as the information exchanged between innovators, consumers, and other actors involved in a new technology (see, for example, Mowery and Rosenberg, 1979; Smits, 2002; von Hippel, 1976). Not only did the technology-push/demand-pull dichotomy seem limiting in this context, but a consensus also began to emerge that both aspects of the dichotomy were necessary, but not sufficient, for innovation to occur (Dosi, 1982; Mowery and Rosenberg, 1979). An additional problem was that definitional issues were persistent in the empirical research (see criticisms in Mowery and Rosenberg, 1979, for example).

Just as the economics of innovation literature moved beyond the technology-push/demand-pull dichotomy, it may be time for environmental innovation researchers to transcend it as well, and for similar reasons. The definitional problems are perhaps easiest to point to, as they have resulted in confusion by both policy practitioners and researchers. For example, the CPUC quotation above implies that the agency considers the main incentive program in the decision – upfront rebates for solar projects – to be a "technology-push" instrument. Since rebates do not directly support the supply of new knowledge in a technology, but rather foster a market for that technology, they should more properly be considered a "demand-pull" instrument. Conversely, the "pull" the CPUC refers to is a research and development (R&D) support mechanism, which is usually termed "technology-push." Similar difficulties arise in the research literature. For example, in an excellent dissertation on government actions with respect to wind power innovation, Sawin categorizes California's R&D effort to map its wind resource as "demand-pull," despite the fact that public R&D is generally categorized as "technology-push." Her rationale is that the effort facilitated the diffusion of renewable energy technologies to the common benefit of actors seeking to exploit the resource (Sawin, 2001, p. 116). Although this is true, using this reasoning more broadly could result in recategorizing any public R&D activity with an applied focus as a demand-pull instrument, since it would ultimately support commercialization and diffusion.

Demand-pull is already a crowded category of instruments in environmental policy, as the greatest public benefit from environmental technologies – unlike some other public good enhancing technologies, such as defense technologies – usually lies in their widest use. This raises the issue of whether a taxonomy that lumps together all market-related environmental policies – a heterogeneous set, to be sure – as a single type of innovation-related instrument is too broad to be of considerable analytical or practical use. The environmental innovation case study literature perhaps reflects this lack of utility; it focuses less on technology-push versus demand-pull than on the effectiveness in inducing innovation of the attributes of (typically demand-pull) policy instruments, such as their efficiency, flexibility, and stringency (for a review of this literature, see Kemp and Pontoglio, 2008).

More troubling than definitional issues, however, is the possibility that technology-push and demand-pull may be insufficient for optimal innovation to occur. If so, a policy focus on these forces alone may miss useful levers to induce environmental technological innovation. In reviews of the environmental economics literature related to innovation (e.g. Jaffe et al., 2002), one detects a tendency for the research community to see innovation as a "black box" – into which R&D inputs flow and out of which commercial technologies diffuse into the marketplace – to the neglect of the intermediary role for supply and demand interactions that limited the utility of the original dichotomy in the economics of innovation literature. It is unclear, however, whether policy-makers generally approach innovation in environmental technologies as a black box to stay outside of, or whether they find it necessary to delve inside that box as a practical matter.

This paper assembles a comprehensive chronology of solar policy in California and its impacts on innovation, where known, and then uses this as a basis for building a new policy categorization. The paper shows that when California policy-makers invest in new solar energy technologies and create markets for these technologies, they do so in more complex ways than simply placing dollars into either the supply or demand-side of a technology. Instead, policy-makers indeed delve inside the black box to work with and concentrate on a number of actors along the innovation source chain, including energy R&D firms, investor-owned utilities, and the building industry, to fulfill government objectives through means ranging from financial incentive "carrots" to penalizing "sticks."

The effort to build a new policy categorization from this material requires categories that encompass the broad range of policy instruments that are employed in practice in order to stimulate environmental innovation. At the same time, it should not abandon the intuitive resonance of the technology-push/demand-pull dichotomy, despite the confusion involved in taking terms that originally pertained to the influence on successful innovations of technological opportunity and user needs and applying these terms as labels for policy instruments. Replacing these terms in this paper are "Upstream Investment," which represents a range of government actions including the traditional technology-push instrument of R&D funding as well as public investments in small businesses in the solar industry, and "Market Creation," which represents many actions formerly defined as demand-pull, ranging from government's becoming a customer for solar technologies to its development of other customers for these technologies.

In addition, the paper introduces a new, third category of environmental innovation policy instrument – "Interface Improvement" – in order to represent government actions which share a focus on improving the boundary-space between innovators and technology consumers. Although this boundary-space is defined by different actors in different technologies, the focus here is on the "interface actor" of the installers of distributed solar energy technologies. In the installation process, knowledge flows from the manufacturers through the installers and to the end-users (as well as to the government through the permitting process). For purposes of increasing the pace of innovation, ideally knowledge would also flow the other direction, so that installers and end-users could help inform manufacturers and inventors about ways to improve their products. To date, there is only anecdotal evidence of the occurrence of this of this type of reverse knowledge-flow. At the same time, there is considerable evidence that opportunism by these actors can be a barrier to the efforts of policy-makers to support innovation in solar energy technologies.

The paper proceeds as follows. The second section of the paper provides background on the solar energy technologies promoted by California, including the actors that serve as sources of innovation in these technologies. The third section explains why California's solar policy is such a rich test case, and then distills a comprehensive chronology of the state's solar policy (included in the Appendix) into the categories mentioned above. Where possible, innovation impacts are discussed in order to help build an empirical knowledge base regarding the effects of policy instruments on innovation. Note that there is much more existing material on the first two categories of instrument than on the third category of instrument, which may well point to an important area for further policy-relevant research. The paper concludes with reflections on the new policy categorization and some possible extensions of this work.

2. Solar energy technologies and innovative actors

Before the mid-1980s, the definition of “solar energy technologies” was quite different than it is today. The term referred not only to technologies powered directly from the sun's energy, but also to technologies powered indirectly from that energy, including wind power, tidal power, and biomass power (relying as it does on the photosynthesis conducted by plants). It also referred to passive solar technologies, which use sunlight for heat and ventilation without assistance from active mechanical systems.

Today, however, the term “solar energy technologies” generally refers to technologies that directly apply energy from the sun to either generate electricity or displace fossil fuel generation at the point of end-use using active means. In the generation of electricity, the most prominent solar energy technologies use either the photoelectric effect, as in the case of photovoltaic (PV) cells, or convert solar radiation to heat that then generates power through such mechanical means as driving a Stirling engine, as in the case of solar thermal electric (STE) power. In displacing fossil fuel generation at the point of end-use, the most prominently supported solar energy technology is domestic solar water heating (SWH), which raises the temperature of a circulating working fluid – sometimes potable water – by exposing it to solar radiation. In most cases, SWH systems work as hybrid systems in conjunction with a supplemental natural gas-powered or electric heater. Note that SWH is similar to the typical application of PV (and passive solar technologies) in its “distributed” nature – it is installed at locations like residences and businesses rather than at larger entities like utilities – in contrast with such “centralized” technologies as traditional coal-fired power plants or STE generating stations.

Table 1 shows recent estimates of the comparative levelized costs and world generating capacity attributed to PV, STE, and SWH technologies in comparison with various fossil fuel and renewable generation technologies. As Table 1 demonstrates, neither of the generating technologies (PV or STE) is inexpensive or in wide use when compared to technologies that utilize fossil fuels, nuclear, or wind power to generate electricity. STE technologies generate electricity at a lower cost than PV, yet provide a smaller percentage of world generating capacity than PV. Until 1998, PV itself mostly served niche markets like consumer products, off-grid residential and rural applications, and communications and signal applications. At that time, small-grid connected electrical generating applications began to exceed these other uses as a percentage of the world PV market (see Maycock, 2004). Meanwhile, domestic SWH is used in 2.5% of worldwide households, although the U.S. market for this technology is minimal despite an excellent solar resource in parts of the country.

Distributed solar energy technologies like PV and SWH involve a longer chain of innovation sources than does the centralized solar energy technology of STE, and there is therefore more room at the interface between innovators and the users of distributed technologies for policies to either intervene or be gamed.[1] Fig. 1 represents the innovative actors in active, distributed solar energy technologies, and provides illustrations of typical PV and SWH systems to provide context. *Inventors/manufacturers* create distributed solar energy technologies and hope to sell them to consumers of various types. *End-users* can purchase these technologies either directly, through retrofit applications that typically use the services of an *installer*, or indirectly, through purchase of a new structure in which they are embedded thanks to *builders* (note that new applications are usually cheaper than retrofits). Theoretically, *utilities* are not naturally in favor of

[1] The primary innovative actors in STE are inventors/entrepreneurs, plant builders, plant operators, and utilities, which serve in the role of first-order customers. Not all of these actors are necessarily distinct from one another.

Table 1
Levelized costs of electricity by various technologies

		¢/kilowatt-hour (kWh)			% of world capacity [a]
		(Badr and Benjamin, 2003) [b]	(Martinot, 2005)	(IEA, 2005) [c]	
Power generation					
Fossil fuels	Coal	–	–	3.5–6.0	24.40%
	Natural gas combined cycle	5.18	–	4.0–6.3	21.20%
	Natural gas simple cycle	15.71	–	–	–
Renewables/ Other	Large hydro	6.04	3.0–4.0	–	18.95%
	Nuclear	–	–	3.0–5.0	6.50%
	Wind	4.93	4.0–6.0 [d]	4.5–14.0	1.26%
	PV	42.72 (50 MW plant)	20.0–40.0 (rooftop PV)	–	0.11% [e]
	STE (trough)	21.53 [f]	12.0–18.0	–	0.01%
Hot water/heating					
	Solar hot water/heating	–	2.0–25.0	–	2.50% of households

Note: "–" indicates that the report gives no clear estimates for this technology.
Source: (Badr and Benjamin, 2003; IEA, 2005; Martinot, 2005).
[a] Fossil fuel and nuclear capacity figures are through the end of 2003 IEA (2005), while the rest are through the end of 2004 (Martinot, 2005).
[b] At 10.8% discount rate.
[c] At 10% discount rate.
[d] This is the on-shore wind estimate. Off-shore wind is 6-10 ¢/kWh.
[e] This percentage is combined off-grid plus grid-connected capacity. Grid-connected capacity alone is 0.05%.
[f] 13.52 with natural gas, to 17.36 with thermally enhanced storage.

distributed solar energy technologies because they displace consumer demand for the centrally-generated power they produce; in essence, the technology offers competition to the utilities in terms of serving the needs of consumers. Note that although the boundaries between these actors are not always distinct – due to vertical integration, for example – in general, these actors have different incentives as agents in diffusing solar energy technology and each presents different potential challenges to policy-makers.

3. Solar policy in California, according to type

California has exhibited considerable market leadership in solar energy technologies. The state is behind only Japan and Germany in terms of its market for PV (Wiser et al., 2007), and is currently the center of a major initiative to promote further diffusion of the technology (see Section 3.2.4.1 below). Fig. 2 depicts the cumulative grid-connected PV capacity in California, as tracked by the California Energy Commission (CEC) between 1981 and 2007. In addition, California was the most important market in the world for STE for decades, and was the most important U.S. market for SWH technology in the 1980s (not to mention the 1900s–20s, when the state was the world's leading market).

Government actions have been a necessary part of the state's leadership in these technologies, as the technologies are not fully cost-competitive in California despite a good solar resource. California's political climate and institutions have, for the most part, been tremendously supportive of solar energy technologies, and since 1974, the state has instituted a vast assortment of policies in support of solar energy. The Appendix presents the most complete compilation and chronology of these policies to date for the period between 1974 and 2006, using a variety of different sources (for a less condensed version of these policies, see Taylor et al., 2007).[2]

The rest of this section distills much of the information contained in the Appendix into three categories of government actions: upstream investment policies, market creation policies, and interface improvement policies. Because of its heterogeneity, the market creation policy category is sub-divided according to the innovative actors involved and the means employed, which primarily include financial incentive "carrots" and penalizing "sticks." In addition, before delving into relevant policies, the interface improvement category discussion highlights some of the installer quality issues in distributed energy technologies, which have not received much attention in the literature. Throughout the section, innovation impacts are discussed, when possible, in order to help build an empirical knowledge base regarding the effects of policy instruments on innovation.

[2] Note that some entries in the Appendix lump together policies and later amendments in a single row due to space constraints.

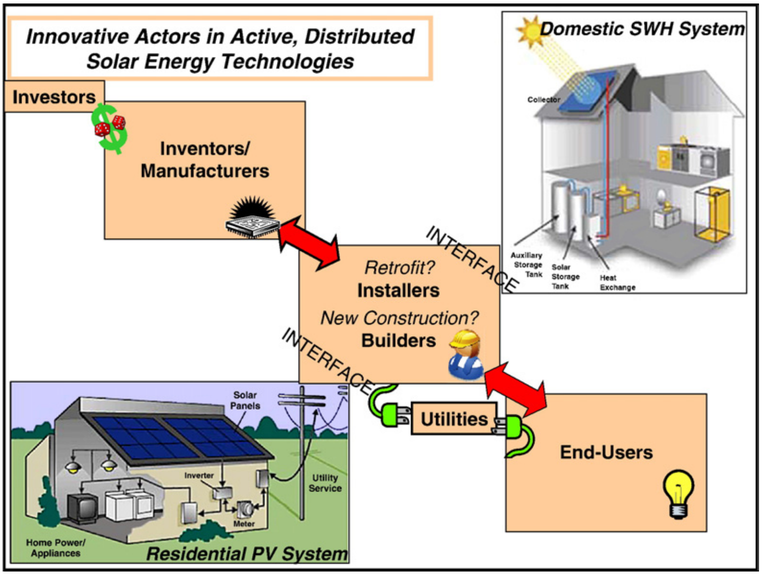

Fig. 1. The innovation source chain of actors in active, distributed solar energy technologies, with illustrations of typical PV and SWH systems (PV and SWH illustrations from City of Columbia, 2007; EERE-DOE, 2005).

Two notes are in order before proceeding. First, the majority of California's policies relate to the more distributed SWH, PV, and, to a lesser extent, passive solar energy technologies, rather than to STE technology. Second, the naming convention for California legislation is "AB" for Assembly Bills and "SB" for Senate Bills.

3.1. Upstream investment policies

In upstream investment policies, government acts to support the supply of new knowledge in solar energy technologies by investing in R&D and providing seed capital to solar companies. California has performed these actions since at least 1974, when it passed AB 1575, the Warren-Alquist Act, which established a broad energy program including research and the accelerated development of solar energy (Sawin, 2001). AB 1575 also gave birth to a new institution, the State Energy Resources Conservation and Development Commission (otherwise known as the CEC), which opened its doors in 1975 (for more on the CEC, see, among others, Hollon, 1980; Talbot and Morgan, 1981; White, 2006). The CEC has been the primary government institution involved in funding solar energy technology R&D in the state. Other important California institutional sources of innovation include the CPUC, which has played an important role in monitoring the R&D investment efforts of the state's Investor-Owned Utilities (IOUs), and the University of California (UC) system. California's energy R&D funding records are, unfortunately, very incomplete and it does not appear to be possible to construct a comprehensive time-series of solar R&D funding. Nevertheless, Fig. 3 is illustrative of the levels of funding the CEC has committed to solar R&D over the years. These levels are significant, and the fact that they are only poorly reported, even in state documents, raises questions about whether systematic undercounting of state contributions to U.S. public energy R&D levels may be one element behind empirical findings that show no clear correlation between these funding levels and innovative outcomes such as national energy intensity and carbon factor (e.g., Sagar and van der Zwaan, 2006).

California has acted to invest in solar R&D not only singly, but also in partnership with private industry, particularly since 1984 when the Rosenthal-Naylor Act established the Energy Technologies Advancement Program (ETAP) at the CEC. This program, which was designed to assist California's energy R&D firms in improving the efficiency and cost-effectiveness of energy technologies, as well as in developing alternative

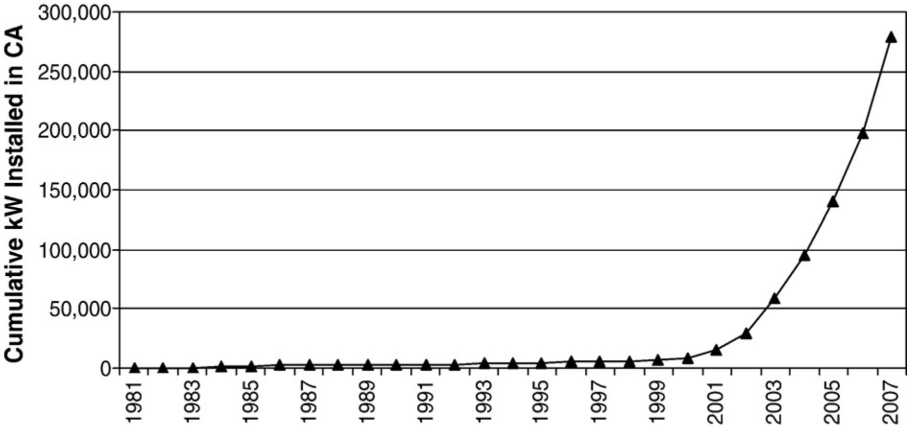

Fig. 2. Cumulative grid-connected PV capacity in California, 1981–07. Source: CPUC (2008a).

sources of energy, leveraged funds from private companies in each project. ETAP also allowed the CEC to obtain repayment of state funds from financially successful projects.[3] The fourth bar in Fig. 3 represents ETAP funding between 1984 and 1991 in PV and STE technologies; unfortunately, more granular data could not be located.

In addition to funding R&D itself, California has also used the CPUC's energy monopoly-regulating powers to mandate that the state's IOUs invest in R&D in solar and other renewables, as well as in R&D in energy efficiency.[4] Total investments by the IOUs in these areas, which began in the 1970s, grew to more than $120 million per year (White, 2006, p. 103). The CEC helped in these efforts by "developing a 'preferred technologies' list for the State … that was reported every two years to be used in the [CPUC's] General Rate Case Review of each IOU's R&D program" (ibid.). When IOUs were not in compliance, fines could be significant. For example, in 1983, the CPUC fined Southern California Edison (SCE) $8 million ($16,653,976 in $2007) for not adequately accelerating its development of renewables (Sawin, 2001, p. 465). As a result of actions like these, California utilities have traditionally led the electric power industry with respect to renewable energy, including solar technologies. Indeed, "through the 1970s, utilities in California were the only ones involved in renewable energy technologies; no private producers were in the picture yet" (Sawin, 2001, p. 171).

The restructuring of the electricity sector in California, however, resulted in reduced ratepayer funded R&D, as utilities had less flexibility and incentive to invest.[5] R&D in advanced generation technologies in California dropped 85% between 1993 and 1995, for example, while contributions from the state's IOUs to the electricity sector's R&D consortium, the Electric Power Research Institute, dropped 50% between 1994 and 1995 (Zucchet, 1995, p. 36). To compensate for the changed IOU R&D incentives under electricity deregulation, the state established the CEC Public Interest Energy Research (PIER) program through legislation passed in 1996 (AB 1890) and 1997 (SB 90).

The CEC PIER program is perhaps the most unusual of the government actions to support solar R&D in California. Instead of a direct exercise of the government's "power of the purse" to invest in R&D, the PIER program is a publicly managed R&D effort that is funded, in a sense, by private industry, as it is dependent on a surcharge collected by the three California IOUs on the retail sale of electricity for its financial support. It is unclear whether PIER has fully compensated for historical IOU R&D efforts, however, as PIER's funding,

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[3] ETAP was successful enough that it was renewed and extended through 2004 in a bill in 1993 (SB 789, the Energy Research, Development, Demonstration, and Commercialization Act).

[4] Today, the three main IOUs are Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E).

[5] California's lengthy restructuring process dates back to 1987, when Stan Hulett, the CPUC Commissioner, began a proceeding to determine "why electric rates in California were 75%–80% above the national average" (Sawin, 2001, p. 175). Although officially, restructuring began when the CPUC issued its 1994 *Order Instituting Rulemaking* (known as the "Blue Book" for its cover's color), a number of bills and CPUC decisions in the late 1980s and early 1990s contributed to it. On December 20, 1995, the CPUC issued its "final" electricity restructuring decision, which became effective at the end of 1996.

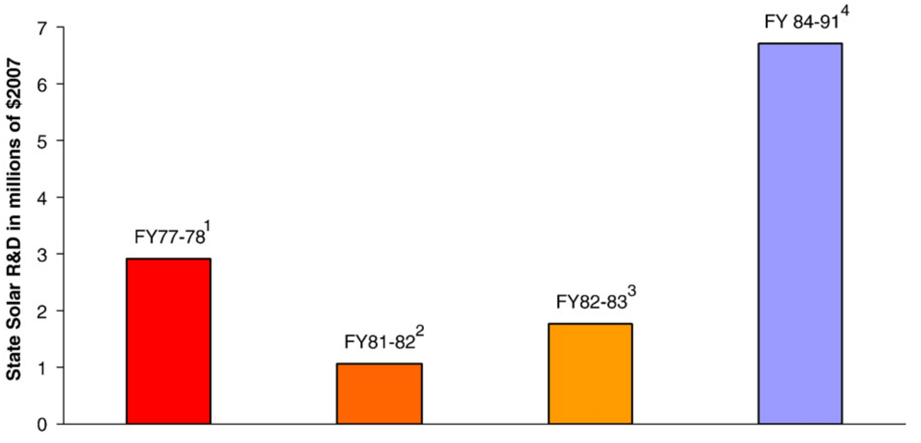

Fig. 3. State solar R&D in selected years, converted to millions of $2007 using the Consumer Price Index. Notes: (1) Proposed fiscal year (FY) 1977–78 state solar R&D, given in $1977 (CEC, 1977); (2) FY 1981–82, given in $1981 (CEC, 1982); (3) Proposed FY 1982–83, given in $1982 (CEC, 1983); (4) Total combined solar thermal and photovoltaics spending in the CEC Energy Technologies Advancement Program, 1984–91, given in $1991 (CEC, 1992).

which was extended in 2002 through 2012, is significantly smaller than the IOU annual funding levels mentioned above, at about $62.5 million (White, 2006).

Finally, California has acted almost like a venture capital "angel" in the past, not just supporting particular technologies but also supporting certain firms. Under the principle that small solar companies have less resilience to volatility in the market for an already expensive technology, in 1980 the California legislature appropriated $2.5 million (about $6.3 million in $2007) to support the California Business and Industrial Development Corporation (BIDCO) to support alternative energy businesses (Galloway, 2000, p. 28). Similarly, in 1982 the legislature appropriated $750,000 to start and operate the non-profit State Assistance Fund for Energy-BIDCO (SAFE-BIDCO) in order to provide loans to small businesses in "any technology or technique which displaces conventional fuels and nuclear energy."

The returns to California of all of this solar energy R&D investment are difficult to quantify. According to patenting activity in the United States Patent and Trademark Office (USPTO) database, which is a well-established metric of innovative output, California intellectual property holders are doing proportionately better in solar energy technologies than in other technology areas. According to 2006 data, while patent assignees from California hold only about 8.7% of total USPTO patents, they hold 22.9% of patents in STE, 14.5% of patents in PV cells, and 14.2% of patents in SWH (Taylor et al., 2007). But very little of this patenting activity is attributed directly to California's government, other than the UC system. The CEC, for example, appears to hold no patents in solar energy technologies (although it does hold several in gas turbine power plants).

3.2. Market creation policies

In market creation policies, government acts to create new customers for solar energy technologies. The innovation effects of such instruments are both direct and indirect. The direct effect is on the diffusion of solar energy technologies, itself a stage of the innovation process, while the indirect effect is on upstream innovative activities like invention and on activities related to positive adoption externalities, such as so-called learning-by-using.

Note that the primary motivation of policy-makers in implementing market creation policies is usually to advance goals like energy independence, reduced costs to electricity consumers, and immediate environmental improvements, rather than to advance innovation in relevant technologies (although the latter is often considered an important secondary goal). As a result, cost-effectiveness analyses of market creation policies usually employ criteria that align with these primary goals, which have somewhat different economic rationales than those used to justify diffusion for the purposes of directly or indirectly inducing innovation.

California has been particularly creative and persistent in its approaches to creating markets for solar energy technologies. It has acted as a customer for these technologies through the state's procurement efforts. It has also acted to create other customers for solar energy technologies, sometimes employing the "carrots" of financial subsidies and sometimes using the "sticks" of mandates or standards with associated penalties. In addition, it has used its monopoly-regulating powers to compel the state's IOUs to create customers for solar energy technologies through programs that mirror these carrots and sticks, to some extent. Because of the heterogeneity of the policy instruments in the market creation category, the category is sub-divided here according to the innovative actors involved and the means employed, including carrots and sticks. When policies in this category are particularly relevant to one set of solar energy technologies over another, the distinction is made in the text.

3.2.1. Government as customer: using procurement policy

In this sub-category of instrument, government creates a niche market for distributed solar energy technologies like SWH, passive solar, and PV by becoming a customer for these technologies through its control over state buildings. The relative size and stability of California's procurement power is potentially quite useful for solar energy technology innovation, not just because of the possibility of capturing economies of scale and spurring positive adoption externalities related to new technologies, but also because it could provide an important customer base on which to build stable solar industry business plans.

Although several procurement policies, including mandates and the issuance of government bonds, have been in place since 1977, when SB 150 established that solar systems should be used in all new state buildings "where feasible," most have not involved absolute mandates (Berman and O'Connor, 1996). For example, although a 1983 bill (AB 1492) authorized public agencies to contract with private energy producers for alternative energy projects, in 1989 a provision was deleted that had limited the lifetime of authorized funds to ten years in order to ensure relatively immediate compliance (Sawin, 2001, pp. 193–5). Similarly, when California's Department of General Services, in consultation with the CEC, established the existing and new building construction standard to require solar energy technology installation on all existing state buildings and parking facilities no later than January 1, 2007 (and on all similar new structures that began construction after December 31, 2002), the "where feasible" provision was again part of the standard (IREC, 2006; Mingyuan, 2005).

No analyses of the role of California's solar procurement policies on solar energy technology innovation could be located for the purposes of this paper. Nevertheless, it is probably reasonable to hypothesize that the state has not reached its full potential as a niche market for solar energy technologies, in part due to compromises in program design and implementation.

3.2.2. Government creates customers: using carrots

In this sub-category of instrument, government acts to create customers for solar energy technologies by using the "carrot" of financial subsidies. The main justification for such subsidies is that end-use customers have a disincentive to implement distributed solar energy technologies like SWH and PV, whether for societal benefit or self-interest, because of the relatively high up-front costs of these technologies.

The most prominent carrot employed in California's solar policy, particularly in the 1970s and early 1980s, was the end-user personal income (or bank and corporation) installation tax credit. First introduced in 1976 in SB 218, California's solar tax credits were modified a number of times before they expired at the end of 1985.[6] Fig. 4 converts Quigley (1991)'s compilation of unpublished California Franchise Tax Board data on these tax credits into millions of $2007 in order to depict the enormity of the state's commitment to these tax credits for solar energy technologies between 1978 and 1983 (Quigley, 1991). Only a small proportion of California tax-payers utilized the credits, however, with relevant total household returns increasing from 16,800 in 1978 to a high of 85,100 returns in 1980 (ibid.); by contrast, the total California population in 1980 was 23,782,000. Assessing these and similar data for wind power investment tax credits in California according to income, Quigley (1991) concludes that California's solar tax credits were both expensive and regressive, with little empirical evidence to demonstrate their effectiveness with regard to energy conservation. They also became

[6] Most of these changes related to modifications of the credit formula, such as 1977's AB 1558, 1985's SB 125, and 1985's SB 1079 (Hollon, 1980; Quigley, 1991), and/or extensions of the credit either in time or with respect to other residential or non-residential applications, like 1980's AB 2036 and 1983's SB 298 (Kinnee, 2005; Quigley, 1991).

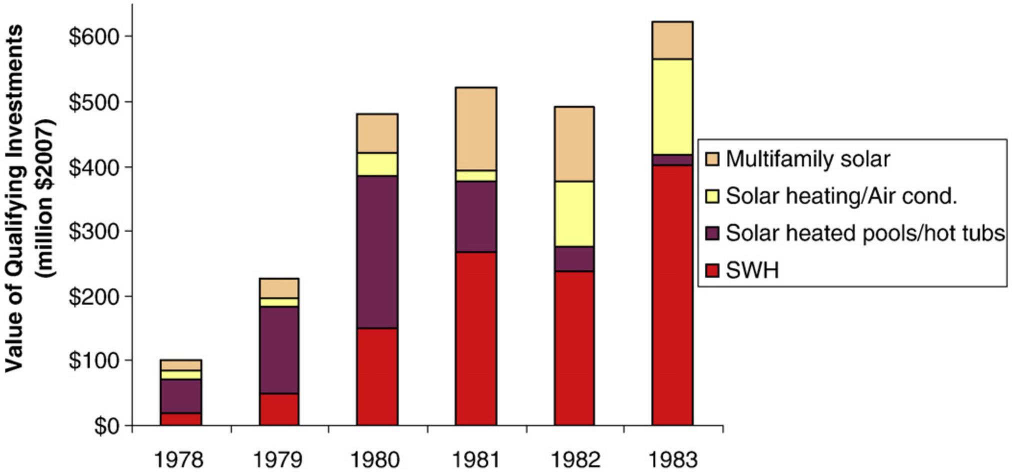

Fig. 4. Domestic solar water heating, solar heated swimming pools and hydrotherapy tubs, solar heating and air conditioning, and multifamily solar investments qualifying for California tax credits, converted to $2007 using the Consumer Price Index. Calculated from Quigley (1991).

politically difficult to continue, particularly after George Deukmejian was elected governor in 1982, in part on a campaign promise to end the state's solar and energy conservation installation tax credits. Although the installation tax credit was resurrected in 2001's SB 17 for a few years, its current importance in California's solar policy is probably in the model it has provided for the technology rebate program currently being funded by IOU ratepayers (which will be discussed in Section 3.2.4 below).

Although the installation tax credit (and its IOU rebate cousin) is probably the policy instrument most familiar to California's end-users of solar energy technologies, the state has employed other financial incentives for technology diffusion as well. These incentives have included interest-free loans for solar energy systems for disaster victims (as in 1978's SB 373), depreciation deductions for solar energy systems (as in 1983's SB 298), and tax credits for the purchase of "solar easements" (as in 1978's AB 3623) (Berman and O'Connor, 1996; Hollon, 1980; Sawin, 2001, p. 193). In another example, in 1983 California invested seed money in the Solar Energy and Conservation Mortgage Corporation (Sunny Mac). A joint project of the savings and loan industry and the solar industry, Sunny Mac was supposed to provide a secondary lending market for SWH loans, following the model of the federal mortgage secondary market corporations (Coe, 1985, p. 207). Sunny Mac's business model was to sell shares to participating lenders, who would then be able to sell their loans to Sunny Mac for slightly less interest than they charged them out. To be successful, however, Sunny Mac needed to sell $3 million in shares in 1983; by October of that year it was clear that this was impossible, and ultimately, the seed money had to be repaid to California.

In addition to emulating a mortgage policy for SWH loans, a number of California's policies focused directly on mortgages, home loans, and the building industry because of the synergies between home building and solar energy technologies. For example, preferential mortgages and home loans are treated in 1978's AB 2225 and 2851. In addition, beginning in 1978 (with AB 3263), builders of new single-family dwellings could claim a 25% tax credit or pass it on to the original buyer; this was later reduced to 15% in 1983's SB 298 (Hollon, 1980; Quigley, 1991). The engineering rationale for subsidizing the building industry with respect to solar energy technologies (and also using mandates and standards on the industry, as discussed in Section 3.2.3, below) is that although it is economically more efficient to employ solar energy technologies in new construction, rather than in retrofit applications, standard building practices do not take this into consideration.

Finally, California's "carrot" approach to solar energy technologies has not always been top-down (i.e. from government leaders down to the people). In 1980, California's voters created a financial incentive for solar energy system construction when they passed Proposition 7, a ballot initiative that amended the state's constitution to give the legislature the authority to exclude such construction from property tax. This property tax exemption was implemented in the Revenue and Taxation Code and made operational from 1981–91 due to 1980's SB 1306 and 1985's AB 1412. It was not extended through the 1993–94 fiscal year thanks to the veto of Deukmejian, who served as governor of California from 1983–1991. The property tax exemption was ultimately reinstated and extended through 1994 after Deukmejian had left office (through 1991's SB 103), then reinstated again in 1998's AB 1755 and extended in 2005's AB 1099; it is currently set to expire on December 31, 2009 (Coe, 1985, p. 199; IREC, 2006).

3.2.3. Government creates customers: using sticks

In this sub-category of instrument, government acts to create customers for solar energy technologies by using the "sticks" of mandates or standards, with associated penalties. Beyond the provision of solar access rights in 1978's AB 3250 and AB 2321, California has not yet directly used such sticks on the main end-users of distributed solar energy technologies (i.e. residential, commercial, and industrial electricity consumers). It has, however, employed this type of instrument to a limited extent on the building industry that shapes the choices these consumers face.[7] The rationale is the same as for the carrots offered to the building industry, discussed above in Section 3.2.2: standard building practices for new construction present a barrier to the diffusion of solar energy technology.

California acted to mandate solar standards in new construction to some degree beginning with AB 2740 in 1976. This action followed the path California had been blazing in the area of energy efficiency building standards, starting with 1972's SB 277 and continuing through the establishment of the CEC and the 1978 introduction of the renowned Title 24 residential building standards. The Title 24 standards themselves became an important tool in driving the incorporation of solar technologies in construction when they were modified in 1981. The modification established "'energy budgets' for single- and multifamily buildings for 16 climate zones throughout the state" (Quigley, 1991). Compliance with the energy budget (expressed in Btu/square foot/year) could be "determined by using an approved set of calculations to estimate annual energy use" or through the installation of one of three "prescribed packages of alternative components in the building" (ibid.). The building design packages differed in their use of passive solar (Package A), active solar water heating (Package C) and compensatory measures for not incorporating passive solar (Package B) (ibid.).

Since 1981, the most important use of building industry mandates to support the diffusion of solar energy technologies has been the 2006 (SB 1) provisions that solar become a "standard option" for buyers of new homes by 2011 and that the CEC consider mandating solar in all new construction (Berman and O'Connor, 1996, p. 30; EIA, 2005).

No analyses of the innovation effects of California's solar mandates on the building industry could be located for the purposes of this paper.

3.2.4. Government creates customers: working through investor-owned utilities (IOUs)

In this sub-category of instrument, government creates customers for solar energy technologies through its regulatory authority overseeing investor-owned utilities (IOUs). Other than California's solar tax credits, this has been the main type of policy employed in the state, and it allows California to not only shape end-user incentives, but also shape IOU incentives that might not naturally be expected to support innovation in these technologies. For example, in the absence of government intervention, IOU incentives might be expected to help lock in existing technologies for reasons that include a lack of competition on the generating side of the utility business, the grid-connection issues with distributed technologies, and a disinclination for utilities to support a reduced demand for its main product, electric power, due to options like SWH and energy efficiency.

Within this sub-category of instrument, California has taken four major policy approaches. First, it has had the IOUs offer "carrots" to the end-users of distributed solar energy technologies in the form of favorable installation rebates. This approach was quite prominent in the early 1980s, and became the state's dominant effort in support of distributed solar energy technologies in the 1990s and 2000s. Second, it has had the IOUs offer "carrots" to centralized solar and other independent energy producers through favorable long-term contracts; these contracts were established as a result of the CPUC's implementation of the 1978 federal Public Utility Regulatory Policy Act ("PURPA") and the agency's instituting of power purchase agreements. This second approach, prominent in the 1980s, has been the most important state effort to support STE for most of

[7] It has also employed the stick with regard to the IOUs. This is one of the government customer creation approaches that will be discussed in the next section.

the past thirty-five years. Third, California has had the IOUs offer “carrots” to end-users of distributed solar energy technologies by providing retail credit for at least a portion of the electricity generated by distributed systems via the instrument of net metering, which has been employed in the state in some form since 1996.[8] Finally, California has employed a “stick” on IOUs by requiring them to purchase a legislated percentage of their total retail electricity sales from renewable sources, including solar energy technologies, through the state's renewables portfolio standard (RPS). California's RPS, which was established in 2002, has promoted STE in the State more than any other instrument since the early 1990s.[9] This reflects the fact that although the RPS is technologically flexible, the kilowatt-hour (kWh) costs presented in Table 1 and the certainty of supplied power favor wind above STE above PV under this policy instrument.

No analyses of the impact on solar energy technology innovation of California's net metering policies or RPS could be located for the purposes of this paper, in part because of the relative youth of these policy instruments when compared to the age of the relevant technologies. As a result, the rest of this section focuses on the first two approaches within this sub-instrument – both carrots – and their impacts on distributed and central solar energy technologies, respectively. For more information about all of these instruments, see the Appendix.

3.2.4.1. Installation rebates. In this policy approach, California has the IOUs create customers for distributed solar energy technologies by offering end-users favorable installation rebates. The rationale for this approach is very similar to that explained in the “carrot” section in 3.2.2, above: end-users have a disincentive to install distributed solar energy technologies because of relatively high up-front costs.

The earliest relevant example is the CPUC's three-year “Demonstration Project,” which was launched in 1980 with the purpose of demonstrating whether “a new energy source could be made available through the existing… energy supply system” (Hollon, 1980). The project aimed to retrofit up to 375,000 residences with SWH by requiring the IOUs to provide a choice to consumers of 6% interest loans or rebates for SWH systems.[10] The Demonstration Project was considered a success in terms of the number of SWH systems deployed (160,000), with various IOU rebate quotas quickly met.[11]

But in terms of helping SWH technology diffuse in the U.S. and ideally, increase its pace of improvement, the Demonstration Project is widely considered a failure. The primary reason for this has to do with misbehaving installers, and will be explored further in the Interface Improvement Policies section below (Section 3.2.4). An important secondary reason, however, is of particular interest regarding the CPUC's direction of IOUs to create customers for solar energy technologies. Coe (1985) points out that the CPUC did not have the administrative capacity to keep up with the tremendous interest in the program:

> “Each program development or change was subject to a public comment period and full Commission review in a regulatory proceeding. In addition to adding to time and complexity, this also increased the cost for all parties involved, who hired lawyers and filed endless briefs on the minutia of the rebate and loan scheme” (Coe, 1985, pp. 209–10).

The main proponent of the Demonstration Project, then-CPUC President Leonard Grimes, concluded that “regulatory agencies such as the CPUC are not appropriate vehicles for instituting such programs, and that they are better done through the legislative process” (Sawin, 2001, p. 190). By 1987, a CPUC report “concluded that continued subsidization of SWH systems was not cost-effective and did not serve the public interest” (Kurokawa and Ikki, 2001).

[8] Although there is a sense in which net metering can be considered a “stick” employed on IOUs because of the mandated amounts of total generating capacity for which they are required to provide net metering contracts, it is justified by policy-makers more by the economics of the end-user decision to install distributed solar energy technologies. Note that since net metering came into effect in California in 1996 (SB 656), the state has: changed the type of meter legislated from one-way to two-way; introduced particularly favorable time-of-use rates; broadened the incentives eligibility from residential to commercial, industrial, and agricultural users; increased the eligible system size; and increased the caps on the total rated generating capacity for which the IOUs are required to provide net metering contracts.

[9] Although the CPUC first decided in 1995 to meet existing renewables mandates through an RPS instead of existing “green marketing” approaches, it wasn't until 2002 that SB 1078 formally established a jointly operated CPUC-CEC program in which IOUs would have to annually increase the renewable portion of their retail portfolios by at least 1% per year until the target of 20% was reached in 2017. In 2006, SB 107 accelerated the RPS target to 20% by 2010. Note that in this context, green marketing refers to the consumer purchase of renewable electricity from either a utility or a green power provider through the electric grid.

[10] San Diego Gas & Electric was exempt from the loan option because of poor finances.

[11] Southern California Edison's quota for single-family residents was met in three weeks, San Diego Gas & Electric's quota for natural gas customers was met in two months, and Pacific Gas & Electric's quota was met by the beginning of 1981 (Coe, 1985, p. 208).

Almost ten years passed before California again began to utilize IOUs to create customers for solar energy technologies via installation rebates, this time in support of PV instead of SWH. In 1996, AB 1890 established an IOU surcharge-funded program known as the Renewable Energy Program (REP) (Sawin, 2001). SB 90, which implemented the REP in 1997, took the $540 million the three IOUs were to collect over four years (1998–2001) of the REP and placed that money into four accounts in the CEC's Renewable Resource Trust Fund.[12] One of these accounts, the Emerging Renewables Program (ERP), was a buydown rebate program that paid residents and small commercial establishments "50% of the system cost or $3/Watt (whichever is cheaper) for the installation of equipment" (Sawin, 2001). The expectation was that ERP payments would drop in parallel with system cost declines, with payments continuing for four years or until the funds were exhausted (ibid). In addition, in 2001 the CPUC began administering the Self-Generation Incentive Program (SGIP), a separate rebate program for larger systems than those covered in the ERP. Between 2001 and the end of 2005, the IOUs that administered the SGIP had paid "or reserved $421 million in rebates to solar projects representing 113 MW of power," and a significant waiting list existed. The CEC, meanwhile, between 1998 and the end of 2005 had "allocated $371 million and [had] provided incentives to over 50 MW of installed systems" (CPUC, 2005–06, pp. 3–4). In January 2007, the CEC/CPUC system-size based rebate system was replaced by a CEC/CPUC building-type based rebate system as part of the Million Solar Roofs program (SB1), which is touted as "the second largest solar incentive program in the world" (CPUC, 2008a).

Although it is premature to analyze the Million Solar Roofs program with respect to solar energy technology innovation, Wiser et al. (2007) analyzed the state's earlier PV rebate programs with respect to the costs of installations, probably the most important shortcoming of PV systems. In considering 18,942 PV systems either funded or approved for funding under the CEC's ERP and the CPUC's SGIP, the authors found "clear evidence that the California market has experienced reductions in PV costs over time" (Wiser et al., 2007). Although some of these cost improvements are because of "decreases in worldwide module costs (notwithstanding the recent increase in those costs)," the authors find that most of the declines are due to "improvements in non-module costs." These costs, which represent about half the total cost of a typical residential PV system, include non-module hardware components as well as supplemental costs involved with installing and maintaining a system.

In contrast to these positive findings regarding PV cost improvements, which the authors are unfortunately unable to "prove conclusively" are due to the state's incentive programs, Wiser et al. (2007) finds "troubling evidence that policy design has adversely impacted" PV system costs. For example, a provision in both the ERP and the SGIP programs that capped the size of the rebate at 50% of the system cost "appears to have, at best, impeded cost reductions, and at worst, contributed to artificial cost inflation" (Wiser et al., 2007). In addition, the authors find that "pre-rebate installed costs have tracked (to some degree) the level of the rebate itself, and that system purchasers have therefore not benefited from the full amount of the rebate (with some of it 'captured' by system retailers or installers through higher prices)" (ibid.). The implication of this is that opportunism by actors at the interface between the technology supplier and consumer has been detrimental to the policy-induced diffusion of PV technologies in this instance.

3.2.4.2. PURPA Implementation and Power Purchase Agreements. In this policy approach, California had the IOUs become customers for solar energy technologies via long-term favorable contracts – a type of financial "carrot" for independent energy producers – which were established as a result of the CPUC's implementation of the 1978 federal Public Utility Regulatory Policy Act ("PURPA") and the agency's instituting of long-term power purchase agreements. Unlike many of the other policies discussed in this paper, this approach primarily benefited STE rather than distributed solar energy technologies.

PURPA removed grid-related barriers to "qualifying facilities" (QFs) by mandating: (1) utilities pay for power from QFs at "avoided costs," or the costs saved by not having to build new power plants, as well as (2) sell back-up power to QFs at non-discriminatory rates. A 1980 Federal Energy Regulatory Commission (FERC) ruling also required utilities to make all necessary interconnections to facilitate energy sales and to "purchase all QF electric energy and capacity regardless of the utilities' needs" (Larson and West, 1996). State utility commissioners were charged with implementing the FERC rules on PURPA, and in 1982, the CPUC rewarded state QFs with high avoided costs that reflected contemporaneous expectations of high future prices for natural gas and oil. After the first ten years at the high rate set in this decision, the purchase price for QF

[12] The fund was renewed for 2003-2006 but has been radically reduced since.

power was set to automatically revert to the actual avoided cost, which was much lower than initially predicted because oil prices dropped considerably during the 1980s. As a result, the price that QFs received after those first ten years dropped dramatically in what is sometimes referred to as the "11–year cliff" (EIA, 2005).

Also in 1982, the CPUC created ten-year power purchase agreements (Standard Offer Contracts) which were designed to address concerns about possible under-supply, given long construction delays in the state's nuclear plants. The contracts were additionally intended to address the delays private developers faced in negotiating purchase contracts with the utilities, which were "reluctant to agree to such contracts because of concerns about viability of projects, and concern that CPUC might not consider the contracts reasonable" (Sawin, 2001). The Standard Offer Contracts Numbers 1–3 that resulted "were based on the notion that there should be no difference in electricity rates regardless of whether the electricity was generated by a utility or by a QF" (Guey-Lee, 1999).[13]

In 1983, the CPUC followed these contracts with interim Standard Offer Number 4 (ISO4) contracts which used long-term avoided costs as the price basis for 15–30 year contracts with the first ten years set at a guaranteed price; payments were to be based on energy produced and capacity installed (Sawin, 2001). The CPUC withdrew the ISO4 contracts in 1985 "due to concerns of excess capacity and overpayments" (ibid). In 1986, the CPUC approved the structure for final Standard Offer Number 4 (final SO4) contracts, but did not issue a final decision until 1992. The final SO4 contracts were never implemented, however, due to the fallout from a 1995 FERC decision to disapprove California's Biennial Resource Plan Update (BRPU) approach to advancing renewable generation within the framework of utility restructuring. In response to a subsequent CPUC complaint that the ruling limited California's ability to engage in resource planning, the FERC reaffirmed its BRPU disapproval, but it ceded that states could pursue favored technologies "as long as such action does not result in rates above avoided cost,"as in so-called "externality adders" to avoided cost calculations (ibid., p. 38). One of the more notable indirect victims of FERC's BRPU disapproval was the last U.S. wind power company in existence at that time.

Experts credit California's PURPA implementation with creating an important foothold for independent energy producers, and the Standard Offer Contracts (especially ISO4) with providing assurance of future earnings for those producers (for more information, see Taylor et al., 2007). In particular, these policies helped Luz, an entrepreneurial southern California firm, to build nine "Solar Electric Generating System" (SEGS) STE plants in the state – the only commercial STE installations in the world, until recently – between 1984 and 1991. During those eight years, the SEGS plants produced 95% of the world's solar-generated electricity, while the levelized cost of that electricity declined from "a reported 24 U.S.¢/kWh to 8¢/kWh" (Lotker, 1991; Mariyappan and Anderson, 2001).[14]

But having the IOUs become customers for solar energy technologies via long-term favorable contracts also introduced negative elements for long-term environmental innovation, however. The 11-year cliffs put QFs in financial uncertainty, for example, and the FERC BRPU disapproval at about the same time compounded that uncertainty. In addition, a seemingly small legislative detail of PURPA had an insidious effect on STE innovation. This detail was a size limit on one of the two categories of QFs, that made the QF exempt from regulation as a utility under state law as well as under the Public Utility Holding Company Act of 1935 (PUHCA). According to a vice-president of Luz, the limit constrained the company from "designing a plant sized at an optimal level" to take advantage of economies of scale (Lotker, 1991). Even two pieces of legislation that raised the limit for different periods of time did not resolve the problem, as the temporary nature of that legislation left a "crucial uncertainty in Luz's future," as "any long-term investor considering supporting Luz would have to carefully examine the likelihood that … new solar electric QFs … would once again be limited" to a sub-optimal size (ibid.).

3.3. Interface improvement policies

In interface improvement policies, government acts to enhance the innovative function of the actors who occupy the position in the innovation source chain between technology inventors/manufacturers and end-users (see Fig. 1). These policies potentially include those that enhance knowledge-flow between these actors and other sources of innovation, as well as those that remove any hindrances to environmental

[13] The Number 2 contracts were suspended in 1986 and the Number 1 and 3 contracts ended with electricity restructuring in 1996.
[14] Sandia National Laboratories is given credit for working effectively in partnership with Luz to bring about these cost declines.

innovation that these actors might present. Although the interface is defined by different actors in different technology cases, the focus here is on the installers of distributed solar energy technologies.[15]

Installers provide retrofit applications of solar systems on the property of end-users by taking equipment from manufacturers, configuring it on building structures, and integrating it with existing infrastructure. In the installation process, knowledge flows from the manufacturers, through the installers, and to the end-users (as well as to the government through the permitting process). For purposes of increasing the pace of innovation, ideally knowledge would also flow the other direction, so that installers and end-users could help inform manufacturers and inventors about ways to improve their products. Although there is anecdotal evidence of this reverse knowledge-flow occurring, no studies of this phenomenon could be located for the purposes of this paper.

There is clear evidence, however, that installers have sometimes hindered the efforts to support innovation in solar energy technologies, particularly when "booms" occurred as a result of policy actions. This section expands on installer issues with distributed solar energy technologies – a relatively unexplored issue – before discussing relevant policy approaches. As early as 1934, New Deal legislation spurred a large demand for SWH in Miami, Florida, which inspired a rush of entry into the SWH business (Laird, 2001). Some of the new entrants did proper installations, but some cut costs with negative results such as leaking roofs, too little hot water, etc. The Federal Housing Administration, which had financed most of the systems, stepped in to check claims against some of these businesses in an early quality assurance program. The SWH industry voluntarily adopted standards in response.

A similar episode occurred in California in 1978, however, when national publicity about a local solar ordinance in San Diego County stimulated another influx of both good and bad SWH installation businesses. Hollon (1980) reported that the bad actors were considered "solar profiteers" who entered the business, performed improper installations, and then exited once the incentive program dried up. Researchers found a 66% turnover in solar businesses in the county between mid-1978 and mid-1979.

A few years later, another solar profiteer situation occurred, this time at the level of the state of California. Shortly before the final details of the CPUC Demonstration Project were announced, 29 of 30 solar energy technology stakeholders interviewed in Hollon (1980) had unfavorable impressions of the program for reasons that included the fear that publicity surrounding it would entice solar profiteers to come to California. As alluded to in Section 3.2.4.1, the publicity and the installation boom that followed corresponded with predicted "abusive sales and marketing techniques" by certain installers (Galloway, 2000). These included what the CPUC considered to be excessively high bids and "lifetime warranty" sales gimmicks, in which the "lifetime" was for the solar installation company, not the SWH system, and end-users were left stranded with maintenance and repair needs and no one to call for assistance (ibid.). The Demonstration Project became notorious by the end of the 1980s, particularly with media accounts of the state Attorney General's (AG's) unsuccessful efforts to prosecute the derelict SWH installation company whose poor SWH financing deals led to the foreclosure of some 1400 homes (later blocked by the AG). In addition, there are claims that about half of the SWH systems installed during the Demonstration Project were no longer functioning after five years.

The innovation result of this was the poisoning of the reputation of SWH technology in California, which often serves as an environmental leader for other states. Since the conclusion of the Demonstration Project, the market for SWH in the United States has been tiny and stagnant, in stark contrast to the worldwide market for SWH (see Table 1). With only a few small firms in the SWH business, talented workers migrated to other industries in what one veteran called the "tragedy of 1985." With those workers went hard-won knowledge by system installers, which that veteran cited as the most important driver of essential improvements to SWH technology (Taylor et al., 2007).

Although the negative effects of profiteering SWH system installers on the development and diffusion of SWH were reasonably well known amongst contemporaneous experts during the heyday of SWH in California, to date there are only hints of problems with installers for PV systems during the current solar technology boom. These hints relate to the cost of PV systems rather than their performance. As mentioned above in 3.2.4.1, Wiser et al. (2007) finds evidence suggesting that system installers may have captured, through higher prices, some of the value of the installation rebates established in California's Emerging Renewables Program.

Over the years, policy-makers have taken two major approaches to dealing with installer quality that are directly relevant to some of the hindrances to innovation discussed here. As depicted in Fig. 5, these

[15] For another example, see the pollution control operator "interface actors" that played a critical role in advancing the environmental technology of sulfur dioxide (SO_2) "scrubbers" for coal-fired power plants through trial and error (Taylor, 2001). These actors complemented the work of technology designers, as well as interacted directly with these more traditional innovative actors in what experts deemed an essential relationship in the innovation process.

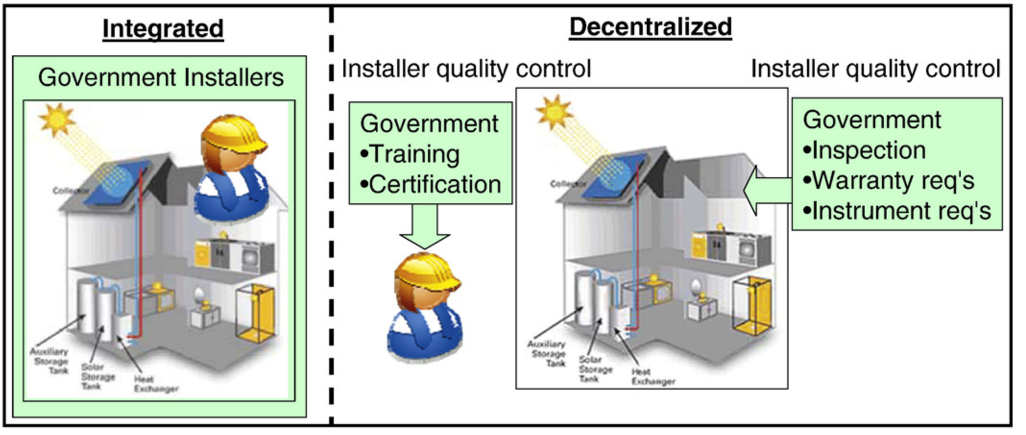

Fig. 5. Options government has employed at the distributed solar interface between manufacturers and technology end-users.

approaches have either been to have government perform the installer function itself – for example, as part of the integrated approach to SWH pursued by California's small number of municipal solar utilities (for more information, see Sanger and Epstein, 1980) – or to have government control installer quality through a decentralized set of policy options. There are two main decentralized options: (1) trying to fashion better installers through training and certification programs; and (2) insuring the quality of the installed system through inspection programs, warranty requirements, the requirement of monitoring technologies, etc. The Appendix lists a number of specific integrated and decentralized policy options for installation quality control that have been employed since the 1970s, and other ideas abound. Hawaii, for example, has had success since the mid-1990s in supporting SWH through a program that makes financial incentives contingent on verification of system performance after installation, at minor additional cost to the government's incentive program.

It is less clear what moves California may have taken to try to reinforce the positive potential of installers as a source of environmental technology innovation. In other technology contexts, for example, the federal government has regularly sponsored conferences in order to advance the development of immature pollution control technologies through formal and informal knowledge exchange amongst such actors as manufacturers, the interface actors of pollution control operators, government, and university researchers. Widely regarded as a critical activity in the development of sulfur dioxide control technology (see Taylor et al., 2003), for example, these conferences might be a model for policy-makers interested in advancing other environmental technologies.

4. Conclusion

The unprecedented scale of the technological transformation required to reduce greenhouse gas emissions to "safe" levels while minimizing economic impacts – on the order of an 80% reduction below 1990 total emissions by 2050 – necessitates an emphasis on designing climate policy to foster, or at least not impede, environmental innovation. But support of innovation has not usually been the primary evaluative criterion for the effectiveness of environmental or renewable energy policy instruments, unlike such criteria as cost to society, immediate pollution reduction, and energy conservation. As a result, there is only a weak empirical base for policy-makers to stand on regarding the comparative innovation effects of various climate policy options, ranging from establishing a value for carbon and then letting the invisible hand work to foster innovation, to assembling a portfolio of instruments that could include R&D funding, tax credits, RPS, and energy efficiency standards.

Empirical scholarship in environmental innovation is impeded by the complexity of both the innovation process and the interactions between the dual market failures of pollution and innovation that are in play, and it appears that the field would benefit from the structure provided by a common lexicon. This paper

Table 2
Types of policies employed in California's solar policy

Policy category	Government action
Upstream investment	• Invests in R&D, sometimes in partnership with private sector. Recently, utility surcharges have provided resources for publicly administered R&D program. • Provides capital to support solar companies, sometimes in partnership with private sector. • Uses monopoly-regulating power to compel utilities to invest in solar R&D.
Market creation	• Acts as a customer for solar technologies through procurement policies for public properties. • Creates customers for solar technologies, either through subsidies or through mandates/standards. • Uses monopoly-regulating power to make utilities become or create customers for solar technologies.
Interface improvement	• Performs the role of installer. • Ensures quality installers through decentralized policies like training and certification programs. • Ensures quality installations through decentralized policies like inspection programs and warranty requirements.

focused primarily on the issues related to policy categorization, which have received little attention in the literature despite their importance to making insights gained from empirical studies generalizable.

The dominant policy typology takes terms used to contrast the influence on the rate and direction of technological change of technological opportunity (technology-push) versus the "calling forth" of innovations in order to meet user needs (demand-pull) and applies them to policies that either fund the supply of new knowledge or create demand for new technologies, respectively. The resulting technology-push/demand-pull *policy* dichotomy has had intuitive resonance, and has served as a useful first step in structuring the way researchers and, perhaps, policy-makers consider the relationship between policy instruments and environmental innovation. But as in the economics of innovation literature, definitional issues related to the terms as they are applied to environmental policy persist. Similarly, as evidenced by the phenomenon described in this paper of profiteering SWH installers scuttling public technology diffusion efforts despite the existence of both technical knowledge and user needs, it appears that in the environmental innovation area, both aspects of the technology-push/demand-pull dichotomy may be necessary, but not sufficient, for innovation to occur.

Renewable energy policy presents particular challenges to the technology-push/demand-pull dichotomy. In traditional environmental technologies like power plant pollution control devices, it is easier to think of government either acting to increase technological opportunity or define user needs. After all, there is little private value to a pollution control technology that functions to serve the public good of clean air. But in renewable energy technologies, private value is mixed in with the public value of the technology, and it is likely to be politically more difficult for government actors to justify implementing "stick" actions like mandates instead of "carrot" actions like subsidies, even if various private actors might try to exploit these subsidies, as in the case of solar profiteers. The history of solar energy policy in California certainly shows a preponderance of "carrots," for whatever reason. This might change, however, if the development of renewable energy technologies becomes driven to a much greater extent by environmental policies like cap-and-trade programs and carbon taxes, which both serve as "sticks," of a sort.

In the meantime, the policy categorization provided in this paper can hopefully assist researchers and policy-makers in peering inside the "black box" of environmental innovation and considering the likely implications of, or need for, government actions to promote such innovation. The categorization developed here on the basis of California's solar policy history is summarized in Table 2. It is hoped that the three main categories will be applicable to environmental technology cases other than solar energy technologies, as they refer to aspects of the innovation source chain that are fairly common across technologies.

Note that at times government performs an innovation-related function like investment itself, while at other times it acts to stimulate the private sector to perform the function instead. The conceptual frameworks of transaction cost economics clearly resonate here, as well as in the bounded rationality of policy-makers and the opportunism of SWH installers described elsewhere in the paper. Employing these frameworks, and those of organizational theory and business strategy more broadly, to understanding the interaction between policy and environmental innovation is likely to prove fruitful in building an environmental innovation empirical research agenda to further the goal of climate safety.

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Appendix A
Solar policy chronology in California

Year	Description of event	Primary policy category
1974	• AB 1575 Warren-Alquist Act establishes “State Energy Resources Conservation and Development Commission” (a.k.a. the California Energy Commission, “CEC”) which opens its doors in 1975.	Upstream investment
1975	• Santa Clara CA establishes first “municipal solar utility” (MSU) in the nation to supply, install, and maintain SWH systems for residents and local businesses. Prompts CEC Solar Office to work with six other California cities to develop plans for further MSUs, which evolved with local circumstances to provide programs ranging from leasing operations to providing energy information (Bereny, 1977, p. 246; Hollon, 1980 pp. 8–9). The CEC and the six cities formed a “joint powers authority” – the California Solar Energy and Conservation Development Authority (CalSECDA) – to help local governments work with MSUs. CalSECDA provided its members with legal advice, education and training programs, and technical consultants.” (Coe, 1985, pp. 204–6).	Interface improvement
	• Jerry Brown elected governor; administration very favorable to solar policy (“Governor Moonbeam”).	N/A: political
1976	• AB 2740 Authorized solar provisions in state building codes (Berman and O'Connor, 1996, p. 30).	Mkt creation “stick”
	• SB 218 Solar income tax credit of 10% or $1000 (whichever lower) off the cost of residential solar equipment installed for heating, cooling, or producing electricity (to expire December 31, 1980).	Mkt creation “carrot”
	• Initiation of Office of Appropriate Technology within Governor's Office of Planning and Research: mission to help develop “small scale, decentralized technologies that rely on renewable energy sources” (Talbot and Morgan, 1981, p. 82).	Upstream investment
1977	• AB 1558 (Hart) Solar income tax credit modified to 55% or $3000, net of federal credits (usually 40%); same expiration date (Quigley, 1991; Hollon, 1980).[16]	Mkt creation “carrot”
	• SB 150 (Alquist) Solar systems to be used in all new state buildings, where feasible (Berman and O'Connor, 1996, p. 30).	Mkt creation: gov't as customer
1978	• AB 3623 Solar income tax credit extended to cover purchase of solar easement. Builders of new single-family dwellings could claim a 25% credit or pass it on to original buyer (Hollon, 1980).	Mkt creation “carrot”
	• Solar Office within CEC runs Testing and Inspection Program for Solar Equipment (TIPSE), which certifies solar collectors for performance and durability.	Interface improvement
	• SB 373 (Rains) Interest-free loans for solar energy systems to disaster victims who are rebuilding their homes (Berman and O'Connor, 1996, p. 30).	Mkt creation “carrot”
	• AB 2225 (Young) Banks, savings & loans (S&Ls) can extend first mortgages, increase new home loans to finance solar systems (Berman and O'Connor, 1996, p. 30).	Mkt creation “carrot”
	• AB 2851 (Wray) Cal-Vet home loans increased by $5000 in allowance for solar installations (Berman and O'Connor, 1996, p. 30).	Mkt creation “carrot”
	• AB 3250 (Levine) Solar Rights Act (Berman and O'Connor, 1996, p. 30).	Mkt creation “stick”
	• AB 2321 (Imbrecht) Solar Shade Control Act (Berman and O'Connor, 1996, p. 30).	Mkt creation “stick”
	• Ballot initiative (Proposition 13) property tax reductions seriously curtail funding levels of the CEC, resulting in “a suspension of funds for the state's renewable energy program” (Sawin, 2001, p. 171).	Mkt creation “carrot”
	• Solar and Insulation Unit of Department of Consumer Affairs established. Weak licensing requirement for installers — no experience or testing required, just form and $35 fee. Today, the Solar Specialty license (C-46), issued by the California Contractors State License Board, requires four years' experience, trade exams, and law exams (IREC, 2006).	Interface improvement
	• San Diego Gas & Electric (SDG&E) begins financing and installing SWH systems on rooftops. California Public Utilities Commission (CPUC) stops the program out of concern whether utilities should behave like banks.	Mkt creation through IOUs

Appendix A (*continued*)

Year	Description of event	Primary policy category
1979	• SB 995 Solar tax credit extended to solar energy systems leased from municipal utilities.	Mkt creation "carrot"
	• CAL SEAL program to label solar installations that meet technical requirements so they can receive tax credits (joint effort of CEC and California Solar Energy Industries Association (CAL SEIA)) (Sawin, 2001, p. 178).	Interface improvement
	• CPUC withholds part of Pacific Gas and Electric (PG&E) rate increase because it considered the company derelict in adopting cogeneration strategies (Watanabe, 1995).	Mkt creation through IOUs
1980	• CPUC launches 3-year "Demonstration Project" to demonstrate whether "a new energy source could be made available through the existing… energy supply system" (Hollon, 1980). The goal was to retrofit up to 375,000 residences with SWH (by the end of the program, 160,000 systems had been installed). To achieve this goal, the state's investor-owned utilities (IOUs) were required to provide a choice to consumers of 6% interest loans or rebates for SWH systems (SDG&E was exempt from the loan option because of poor finances). There were no restrictions on which installers could be used for the SWH systems, although the systems themselves were required to have five-year warranties. The utilities were required to: (1) run inspection programs to check that installed systems operated properly, (2) educate the public about SWH, and (3) purchase and be responsible for installing 2000 units for eligible low-income customers. The project was catalyzed by the CPUC president, Leonard Grimes, in an effort to provide utility customers with "an independent means of lowering their bills." (Hollon, 1980, p. 71).	Mkt creation through IOUs: installation rebates
	• SB 1725 establishes State Office of Appropriate Technology to advise governor & agencies (office to expire June 30, 1984).	N/A
	• AB 2036 Extended solar tax credit to 12/31/83 and expanded it to include all residential applications (formerly just single-family homes). Gradually reduced credits for "recreational or therapeutic SWH systems" from 55% in 1980 to 25% in 1983 (Quigley, 1991, p. 332).	Mkt creation "carrot"
	• Ballot initiative (Proposition 7) passes that amends state's constitution to give legislature authority to exclude construction of solar energy systems from property tax. Implemented in section 73 of the Revenue and Taxation Code and made operational from fiscal year 1981–82 through 1990–91 due to SB 1306 (Stats. 1980, Ch. 1245; Alquist) and AB 1412 (Stats. 1985, Ch. 878; Wyman). Deukmejian vetoed an extension through the 1993–94 fiscal year, but SB 103 (Stats. 1991, Ch 28; Morgan) in 1991 extended it for 1991–92 through 1993–94 when Deukmejian was no longer in office. The property tax exclusion expired on January 1, 1995 but was reinstated in AB 1755 (Stats 1998, Ch. 855; Keeley) for fiscal years 1999–2000 through 2004–5 (Coe, 1985, p. 199). AB 1099 extended it, through December 31, 2009 (IREC, 2006).	Mkt creation "carrot"
	• California begins issuing bonds "to finance the acquisition, construction, and installation of facilities using alternative energy technologies or sources for electricity generation" (Galloway, 2000, p. 28). In 1994, SB 215 increased the limit on financing assistance from \$200 million to \$350 million (Sawin, 2001, p. 185).	Mkt creation: gov't as customer
	• Legislature appropriates \$2.5 million to support the California Business and Industrial Development Corporation (BIDCO), which was designed to support alternative energy businesses (Galloway, 2000, p. 28). In 1982, the legislature appropriated \$750,000 to start and operate the State Assistance Fund for Energy-BIDCO, more commonly known as SAFE-BIDCO. This state-owned non-profit provides loans to small businesses in "any technology or technique which displaces conventional fuels and nuclear energy." As of 2000, the loans were for five years at 5%.	Upstream investment
1981	• Title 24 modified to establish "'energy budgets' for single- and multifamily buildings for 16 climate zones throughout the state" (Quigley, 1991). Compliance with the energy budget (expressed in Btu/square foot/year) could be "determined by using an approved set of calculations to estimate annual energy use" or through the installation of one of three "prescribed packages of alternative components in the building" (ibid.). The building design packages differed in their use of passive solar (Package A), active solar water heating (Package C) and compensatory measures for not incorporating passive solar (Package B) (ibid.).	Mkt creation "stick"
1982	• CPUC rewards state "qualifying facilities" (QFs) – independent energy producers under the federal Public Utility Regulatory Policies Act of 1978 (PURPA) – with rates based on high utility "avoided costs" (costs saved by not having to build new power plants) determined from projections of high future prices for natural gas & oil. [17] After ten years, the price that QFs received reverted back to actual avoided costs.	Mkt creation through IOUs: long-term contracts
	• CPUC creates Standard Offer Contracts Numbers 1–3 – ten-year power purchase agreements – at a price of 6–9 cents/kWh based on the premise that "there should	Mkt creation through IOUs: long-term contracts

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Appendix A (*continued*)

Year	Description of event	Primary policy category
1982	be no difference in electricity rates regardless of whether the electricity was generated by a utility or by a QF" (Guey-Lee, 1999) [18] Standard Offer Number 2 contracts were suspended in 1986 when the world oil market crashed. Standard Offer Numbers 1 and 3 contracts ended with restructuring in 1996.	
	• George Deukmejian elected governor in part on campaign promise to end state solar and energy conservation tax credits.	N/A: Political
1983	• CPUC authorizes Interim Standard Offer Number 4 (ISO4) contracts for QFs using long-term avoided costs as the price basis for long-term guarantees (a 15–30 year contract with the first ten years at a guaranteed price) of payments based on energy produced and capacity installed (Sawin, 2001, p. 172). One analysis calculated that these contracts guaranteed an effective tariff of $0.12/kWh (Sawin, 2001, pp. 470, 480, 176). The CPUC withdrew the ISO4 contracts in 1985 "due to concerns of excess capacity and overpayments" (Sawin, 2001, p. 172, 76; Rader and Bossong, 1990, pp. 51–2). The CPUC approved the structure for "Final Standard Offer Number 4" contracts in 1986, but the final decision was not issued until 1992. They were never implemented due to the fallout from a Federal Energy Regulatory Commission (FERC) decision on California's approach to advancing renewable generation within the framework of utility restructuring.	Mkt creation through IOUs: long-term contracts
	• The Solar Energy and Conservation Mortgage Corporation (Sunny Mac) receives seed money from California. A joint project of the S&L industry and the solar industry, it was supposed to provide a secondary lending market for SWH loans. (Coe, 1985 p. 207) Modeled after the federal mortgage secondary market corporations, its business model was to sell shares to participating lenders, who would then be able to sell their loans to Sunny Mac for slightly less interest than they charged them out. It needed to sell $3 million in shares in 1983 in order to get started; by October of that year it was clear that the goal was impossible to meet that year, and ultimately, the seed money had to be repaid to California.	Mkt creation "carrot"
	• CPUC fines Southern California Edison (SCE) $8 million for not adequately accelerating its development of renewables (Sawin, 2001, p. 465).	Mkt creation through IOUs: "sticks"
	• State budget extends solar tax credit to 12/31/86 and reduces credit to 50% for solar systems up to $3000 net of federal credits. Eliminates all credits for solar heating of swimming pools and spas. (Quigley, 1991, p. 332).	Mkt creation "carrot"
	• SB 298 Lowered credit for builders of single-family dwellings who claim credits (instead of passing them on) from 25% to 15%. Expanded eligibility of leased solar systems, (important for the MSUs). (Quigley, 1991, p. 332) Also expanded tax credit for non-residential properties to all installations, rather than just those costing $12,000 or more (Kinnee, 2005). Extends from 36 to 60 months "the period over which a depreciation deduction for the cost of a solar energy system may be allowed" (Sawin, 2001, p. 193).	Mkt creation "carrot"
	• AB 1942 authorizes public agencies to contract with private energy producers for alternative energy projects (Sawin, 2001, p. 193).This was amended in 1989 to delete the "limitation that authorized funds for alternative energy systems … in state agencies be used within a ten-year period" (ibid. p. 195). In later years, California mandated additional solar in new and existing construction. The existing and new building construction standard, established by the California Department of General Services in consultation with the CEC, requires solar energy equipment installation on all existing state buildings and parking facilities (where feasible), no later than January 1, 2007. It similarly mandates installation in all new state buildings and parking facilities that begin construction after December 31, 2002 (IREC, 2006; Mingyuan, 2005).	Mkt creation: gov't as customer
1984	• Rosenthal-Naylor Act establishes Energy Technologies Advancement Program (ETAP) at CEC (program starts in 1985). Designed to assist California energy research and development companies in making energy technologies more efficient or cost-effective and develop alternative sources of energy, ETAP leverages funds from private companies toward each project. ETAP also allows the CEC to obtain repayment of state funds from financially successful projects.	Upstream investment
1985	• SB 125 Basis for solar tax credit shifts from net to gross of federal credit (federal credits expire at the end of 1985).	Mkt creation "carrot"
	• SB 1079 State solar tax credit set to 10% for single-family residential, 5% for multifamily residential with no maximum credit per unit, 25% for commercial/industrial credit. Set to expire 12/31/86. (Quigley, 1991, p. 332).	Mkt creation "carrot"

Appendix A (*continued*)

Year	Description of event	Primary policy category
1987	• CPUC Commissioner begins a proceeding to determine "why electric rates in California [are] 75–80% above the national average" (Sawin, 2001 p. 175). This helps spur the move to electricity restructuring.	Mkt creation through IOUs
	• CPUC report concludes that continued subsidization of SWH systems not cost-effective, not in the public interest.	Mkt creation through IOUs: installation rebates
1989	• CPUC institutes first Biennial Resource Plan Update (BRPU) intended, in part, to lead to Final Standard Offer Number 4 contracts. At the start of each BRPU, the three participating utilities – PG&E, SCE, and SDG&E – were required to identify new generating capacity needs for the next twelve years. "The CPUC would then identify avoidable plants, and utilities were to respond by announcing the availability of long-run Standard Offer Contracts based on the capacity, and fixed and variable costs, of the avoidable resource. Utilities had to bid to fill their capacity needs, with separate auctions for a required renewables portion" (Sawin, 2001, p. 176).	Mkt creation through IOUs: long-term contracts
1990	• AB 3995 requires "the development of renewable energy sources and the inclusion of environmental costs and benefits in … future energy resource calculations" (Zucchet, 1995, p. 37) In response, the CEC and CPUC both issued values for air pollution from electricity generation and the CPUC further stated that these environmental externality values should be included both in QF purchases and in utility long-term generation purchases (ibid).	Mkt creation through IOUs: long-term contracts
1991	• AB 2198 requires "State and municipal electric resource acquisition programs to include a value for the resource diversity provided by renewables" (Sawin, 2001, p. 176).	Mkt creation through IOUs: long-term contracts
	• AB 1090 requires "the CPUC to set aside a specific portion of future capacity for renewable resources until the Commission devised a procurement methodology that valued the environmental and diversity costs and benefits associated with various generation technologies" (ibid.).	Mkt creation through IOUs: long-term contracts
1993	• BRPU energy auction begins. Bidding irregularities lead to a suspension of the auctions, based on a motion filed by SCE; this suspension was made permanent in 1995 as a result of a FERC decision. In that decision, the FERC made a determination on a case involving SCE and SDG&E which "disapproved" the BRPU. FERC said that the auction process, which only allowed QFs – instead of all potential generation sources – to participate, in effect "set rates above the current avoided cost of capacity and energy" (Zucchet, 1995, p. 37). The CPUC complained that the FERC overstepped its authority in making this determination, as it limited California's ability to engage in resource planning. Although FERC later reaffirmed its decision in the face of this complaint, it did cede that states can pursue favored technologies "as long as such action does not result in rates above avoided cost," as is the case in so-called "externality adders" to avoided cost calculations (ibid., p. 38). As a result of this decision, no FSO4 contracts were ever implemented (Sawin, 2001, p. 177) and QFs faced financial problems given the coincidental timing of the FERC decision with the pending 11-year "cliffs" of avoided costs written at 6–9 cents/kWh dropping off to 3–4 cents/kWh (Allen, 2005). The BRPU cancellation effectively stopped "1500 MW of new QF capacity, almost 600 MW of which was to be provided by renewables" (ibid). Finally, California's approach to renewable generation shifted considerably, with the CPUC "proposing that utilities keep and promote their current use of renewable energy through quantity mandates rather than price mandates" (ibid., p. 31).	Mkt creation through IOUs: long-term contracts
	• SB 789 Energy Research, Development, Demonstration, and Commercialization Act extended operation of the Rosenthal-Naylor Act through 2004.	Upstream investment
1995	• SB 656 is the first net metering law in California (comes into effect January 1, 1996). Simplified the grid interconnection rules for PV systems as large as 10 kW and provided that residential customers operating a "solar electrical generating facility" <1 MW would be able to receive standard contracts at retail prices for the generation they produced from any utility in the state (Wiser et al., 1998, p. 470). As originally established, net metering meant using a "single, nondemand, non-time-differentiated meter to measure the difference between the electricity supplied by a utility and the electricity generated by an eligible customer-generator and fed back to the utility over an entire billing period." Net metering contracts were to be made available to "eligible customer-generators on a first-come, first-served basis until the time that the total rated generating capacity owned and operated by eligible customer-generators in each utility's service area equals 0.1% of the utility's peak electricity demand forecast for 1996" (ibid.).	Mkt creation through IOUs: net metering
	• CPUC issues "final" electricity restructuring decision on December 20th (becomes effective at end of 1996). As part of this decision, the CPUC decides to meet existing	Mkt creation through IOUs: RPS

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Appendix A (*continued*)

Year	Description of event	Primary policy category
1995	renewable mandates through a renewables portfolio standard (RPS), rather than simply rely on "green marketing" approaches to electricity customers (Sawin, 2001, pp. 484–5). Legislation preempts this decision within the year. Note that the Renewables Working Group the CPUC set up to help consider RPS implementation did not unanimously support the RPS.	
1996	• AB 1890 establishes the renewables approach under restructuring. Includes the preferred option of the Renewables Working Group dissenters: a surcharge-funded program (Sawin, 2001, pp. 484–5) rather than an RPS. This program, which was initially established to support different categories of renewables in the state "during the four year restructuring transition period starting January 1998," centered on the CEC and what was to become known as the Renewable Resource Trust Fund (RRTF) (ibid., Wiser et al., 1998, p. 470). The initial Renewable Energy Program (REP), which was funded by the three IOUs (PG&E, SCE, and SDG&E) collecting a distribution surcharge from their customers, was used to support various categories of renewables.	Mkt creation through IOUs, including installation rebates
1997	• SB 90 took the $540 million the three IOUs were to collect in four years (1998–2001) of the surcharge program and placed that money into the RRTF, which was to be distributed in four accounts: (1) the Existing Renewable Resources Account; (2) the New Renewable Resources Account; (3) the Emerging Renewable Resources Account; and (4) the "Customer-Side Renewable Resource Purchase Account" (Wiser et al., 1998, p. 471). The CEC provided additional details concerning the RRTF in late 1997 (the year before it was to begin operating), setting out the percentage of funds to be distributed to the Existing (45%) and Customer-Side (15%) accounts, and establishing that the Emerging account would be unique among the accounts as a buydown rebate program (Sawin, 2001, p. 485).[19] The Customer-Side account was to both educate and incentivize customers to purchase renewable energy, either through distributed generation or through the "green power" market. In support of the green power option, all energy service providers were to disclose their fuel sources (CEC 2005, p. 3). In addition, in 1998, a customer credit of 1.5 ¢/kWh was offered to California customers of renewable electricity generated in California by entities other than utilities, if sold by a "registered electric service provider" (IREC, 2006). In 2000, this credit was reduced to a rebate of 1 ¢/kWh, with some customers having "a ceiling of $1000/year" (Sawin, 2001, p. 486). Also in 2000, AB 995 and SB 1194 extended the system benefits surcharge program through 2011 at the annual level of $135 million (as established in AB 1890 (CEC 2005, p. 3)).	Mkt creation through IOUs, including installation rebates
1998	• CEC Public Interest Energy Research (PIER) program is established with the surcharge to help replace utility funding of R&D lost as a result of electricity restructuring.[20]	Upstream investment
	• AB 1755 adds small commercial customers (up to 10 kW) to net metering eligibility. It also modified the manner in which net metering would be accomplished, "using a single meter capable of registering the flow of electricity in two directions," and allowing for "an additional meter or meters to monitor the flow of electricity in each direction" to be installed (ibid.).	Mkt creation through IOUs: net metering
2000	• AB 918 provides for customer-generators "taking service under tariffs employing 'baseline' and 'over baseline' rates" or "taking service under tariffs employing 'time of use' rates," to have the net kWh they produced or consumed priced accordingly under net metering. So-called "time-of-use" net metering has proven especially favorable to solar technologies, as these technologies often generate the most electricity at times of peak electricity demand.	Mkt creation through IOUs: net metering
	• AB 970 causes the CPUC to create the Self-Generation Incentive Program (SGIP) in 2001. This provides payments ranging from $1/W – $4.50/W to incentivize power production from systems larger than 30 kW (primarily businesses) (CEC, 2005).	Mkt creation through IOUs: installation rebates
2001	• AB 29 raises the eligible system size for net metering from 10 kW to 1 MW and expands the eligible customer-generators to include commercial, industrial, and agricultural customers (Wiser et al., 1998, p. 470).	Mkt creation through IOUs: net metering
	• SB 17 establishes tax credits for solar and wind energy systems under both the Personal Income Tax Law and the Bank and Corporation Tax Law. These credits were to be the lower of "(a) either 15% or 7.5% of the net cost paid" to purchase and install a solar energy system in California, or (b) $4.50 "per rated watt of [rated peak] generating capacity of that same system," up to 200 kW (CEC, 2005, p. 2). The 15% credit was available from January 1, 2001 to December 31, 2003; in tax years 2004–2005, the credit was reduced to 7.5% (ibid.). The credits ended with systems completed before 1/1/06.	Mkt creation "carrot"
2002	• SB 1038 authorizes "the CEC to use [surcharge] funds for the continued administration and support of the REP from 2002 through 2006"; the "REP retained its basic structure … when it recommenced in 2003" (ibid., pp. 3–4). The four main elements of the REP stayed	Mkt creation through IOUs, including installation rebates

Appendix A (*continued*)

Year	Description of event	Primary policy category
2002	more or less the same, although with different percentage allocations: (1) the Existing Renewables Facilities Program (20%); (2) the New Renewable Facilities Program (51.5%); (3) the Emerging Renewables Program (26.5%); and (4) the Consumer Education Program (2%) (IREC, 2006).[21] The Customer Credit Program, which had "provided incentives to consumers who purchased renewable energy in the direct access market," was discontinued "pursuant to SB 1038" and reallocated to the Emerging Renewables Program and Consumer Education Program in 2004 (CEC, 2005, pp. 3–4). The Consumer Education Program offers grants and contracts for public awareness of renewable energy, as well as helps track and verify "renewable energy purchases under the RPS" (Mingyuan, 2005; CEC, 2006). Section 14 establishes that the New program will offer Supplemental Energy Payments (SEPs) "for up to ten years to renewable generators for the above-market costs of meeting the RPS requirements" (CEC, 2005, p. 2; IREC, 2006). This provision was only to become operative if "either, or both, Senate Bill 1078 or Senate Bill 1524 of the 2001–02 Regular Session of the Legislature is enacted and becomes effective on or before January 1, 2003" (SB 1038).	
	• SB 1078, which establishes the state's comprehensive RPS, was signed into law in September 2002. It replaced the goal of 17% renewable energy generation by 2006 (established in SB 1038), with a standard requiring "retail sellers to increase the amount of renewable energy in their portfolios by at least 1% per year, toward a target of 20% renewables by 2017" (Del Chiaro, 2006). As a result of IOU progress in meeting the RPS, the CEC and CPUC have worked to accelerate this timetable; the current RPS involves the IOUs and municipal utilities increasing their share of renewables by 2% per year, starting in 2003, with a goal of 20% renewable energy generation by 2010 and, ultimately, 33% by 2020 (Haas, 2003).	Mkt creation through IOUs: RPS
	• AB 58 caps the total rated generating capacity for which the utilities are required to provide net metering contracts at 0.5% "of the electric service provider's aggregate customer peak demand."	Mkt creation through IOUs: net meeting
2003	• AB 1685 extends the SGIP through 2007. By the end of 2005, the IOU's which administer the SGIP had paid "or reserved $421 million in rebates to solar projects representing 113 MW of power since 2001," and the CEC had "allocated $371 million and has provided incentives to over 50 MW of installed systems since 1998" (CPUC D05-12-044, pp. 3–4). Both programs have "encumbered their expected funding allocations, requiring additional funds to be transferred to the programs" and there is a PV waiting list under the SGIP because of excess demand (ibid).	Mkt creation through IOUs: installation rebates
2004	• AB 135 authorizes "the use of an additional $50 million of RRTF dollars for the Emerging Renewables Program" to assist "in supporting the ongoing demand for rebates" by California customers (CEC, 2005, p. 3).	Mkt creation through IOUs: installation rebates
2005	• In December 2005 CPUC Chair Michael Peevey issues a decision (05-12-044) on an "Interim Order Adopting Policies and Funding for the California Solar Initiative" (CSI). This increased the SGIP funding for 2006 by $300 million, using that money to reduce the PV waitlist (created at incentive levels of $3.50/W) by providing reduced incentives to waitlisted projects of $3.00/W and incentives to new applicants of $2.80/W, the same as in the Emerging Renewables Program.	Mkt creation through IOUs: installation rebates
2006	• In January 2006, CPUC Chair Michael Peevey issues a decision (06-01-024) to establish the CSI as a program to "provide up to $2.8 billion in incentives for solar projects of all types and sizes over 11 years" in order to "bring on line or displace 3000 MW of power" by 2017 (CPUC, 2005–06). The CSI replaces the solar portions of the ERP and the SGIP, although both the CPUC and the CEC remain important actors. The January decision also included an allocation "up to 5% of each year's adopted budget to [research, development, and demonstration] that explores solar technologies and other distributed generation technologies that employ or could employ solar for power generation and storage or to offset natural gas usage"; some of that money is to be used to study and build "market development strategies." In August, the CPUC decided the shape of its part of the program, which is IOU-administered and directs IOU-generated financial incentives ($2.167 billion over ten years from utility revenues from gas and electric distribution rates) to existing homes and existing and new commercial, industrial, and agricultural properties in IOU service areas (CPUC, 2008a). Meanwhile, the CEC directs incentives ($400 million over ten years) to new home construction in IOU areas. An important aspect of the CSI program is that it represents a move away from installation incentives and toward so-called	Mkt creation through IOUs: installation rebates

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Appendix A (*continued*)

Year	Description of event	Primary policy category
2006	"performance-based incentives" (PBI), with some size-based distinctions regarding incentive levels (CPUC, 2008a). Starting in January 2007, projects greater than or equal to 100 kW are paid flat "monthly [PBI] payments based on recorded kW hours (kWh) of solar power produced over a 5-year period," while projects smaller than 50 kW are paid via an up-front incentive – the expected performance-based buydown (EPBB) payment – "based on an estimate of the system's future performance" (CPUC, 2008b). Systems under 50 kW can, however, choose PBI payments. Meanwhile, beginning in January 2008, all projects 50 kW or larger must take the PBI. The CPUC expects that budgets in early years will be relatively high, dropping off over time "as rebate levels fall and, hopefully, as the market's need for financial support decreases." If demand exceeds targets, the CPUC plans to "automatically reduce incentive payment levels each year by 10% or more," while hopefully leaving staff experts flexibility regarding actual incentive reductions in any given year.[22]	
	• SB 1, the "Million Solar Roofs" bill, raises the cap on net metering from 0.5% of peak aggregate demand to 2.5%, while stipulating that to truly achieve 3000 MW of solar power from roofs (the estimated capacity of a million roofs), 5% will be necessary (EIA, 2005). SB 1 also mandates that solar becomes a "standard option" for buyers of new homes by 2011, requires consideration by the CEC of mandating solar in all new construction, and reduces the CSI budget by $800 million to support municipal utilities in developing their own solar rebate programs (ibid.).	Mkt creation through IOUs: net metering

References

Allen, T., 2005. Legislation. The Rahus Institute. Californiasolarcenter.org.

Badr, M., Benjamin, R., 2003. Comparative cost of California Central Station Electricity Generation Technologies, Final Staff Report. CEC Electricity Analysis Office.

Bereny, J., 1977. Survey of the Emerging Solar Energy Industry. In: Winter, F.D. (Ed.), Solar energy information services (San Mateo CA).

Berman, D.M., O'Connor, J.T., 1996. Who owns the sun? People, politics, and the struggle for a solar economy. Chelsea Green Publishing Co., Vermont.

Bush, V., 1945. Science the endless frontier: A report to the President on a program for postwar scientific research. National Science Foundation, Washington, D.C.

CEC, 1977. Biennial report.

CEC, 1982. Exploring new energy choices for California. California Energy Commission.

CEC, 1983. Exploring New energy choices for California. California Energy Commission.

CEC, 1992. Energy development report 1992, Appendix. California Energy Commission.

CEC, 2005. Annual project activity report to the legislature, Renewable Energy Program CEC, Sacramento, CA.

CEC, 2006. History of the renewable energy program. California Energy Commission, Sacramento, CA.

City of Columbia, M., 2007. Diagram of typical solar water heater installation. Columbia Water and Light.

Coe, G., 1985. California's experience in promoting renewable energy development. In: Sawyer, S.W., Armstrong, J.R. (Eds.), State Energy Policy: Current Issues, Future Directions. Westview Press, Boulder, CO, pp. 193–211.

CPUC, 2005-06. Decisions regarding the CSI.

CPUC, 2008a. California Solar Initiative California Public Utilities Commission staff progress report April 2008.

CPUC, 2008b. California Solar Initiative California Public Utilities Commission staff progress report January 2008.

Del Chiaro, B., 2006. California passes million solar roofs bill. Environment California.

Dosi, G., 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Research Policy 11, 147–162.

EERE-DOE, 2005. A consumer's guide to energy efficiency and renewable energy. Energy Efficiency and Renewable Energy, U.S. Department of Energy.

EIA, 2005. Policies to promote non-hydro renewable energy in the United States and selected countries. Energy Information Administration. U.S. Department of Energy, Washington, D.C.

Gallagher, K.S., Holdren, J.P., Sagar, A.D., 2006. Energy-technology innovation, pp. 193–237.

Galloway, J.H., 2000. Policies and programs to support solar water heating systems: An analysis with a case study of a municipal solar utility in Santa Clara, California, Energy and Resources Group. University of California, Berkeley, Berkeley, p. 85.

Grubler, A., Nakicenovic, N., Victor, D.G., 1999. Dynamics of energy technologies and global change. Energy Policy 27, 247–280.

Guey-Lee, L., 1999. Renewable energy 1998: issues and trends; Renewable electricity purchases: History and recent developments U.S. Department of Energy, Energy Information Administration, Washington, D.C.

Haas, R., 2003. Market deployment strategies for photovoltaics: an international review. Renewable and Sustainable Energy Reviews 7, 271–315.

Hollon, J.K., 1980. Solar energy for California's residential sector: Progress, problems, and prospects, Institute of Governmental Studies Research Report 80-3. University of California, Berkeley, Berkeley.

IEA, 2005. Projected costs of generating electricity — 2005 Update. IEA, Paris, p. 232.

IREC, 2006. Database of state incentives for renewable energy (DSIRE). North Carolina Solar Center.

Jaffe, A.B., Newell, R.G., Stavins, R.N., 2002. Environmental policy and technological change. Environmental & Resource Economics 22, 41–69.

Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A tale of two market failures: technology and environmental policy. Ecological Economics 54, 164–174.
Kemp, R., Pontoglio, S., 2008. The innovation effects of environmental policy instruments – a typical case of the blind men and the elephant, DIME WP 2.5 Workshop on Empirical Analyses of Environmental Innovations Fraunhofer Institute for Systems and Innovation Research (ISI), Karlsruhe, Germany.
Kinnee, R.M., 2005. Analysis of Senate Bill 1017 (Campbell) Staff Legislative Bill Analysis. State Board of Equalization, Sacramento, CA.
Kurokawa, K., Ikki, O., 2001. The Japanese experiences with national PV system programmes. Solar Energy 70, 457–466.
Laird, F.N., 2001. Solar energy, technology policy, and institutional values. Cambridge University Press.
Larson, R.W., West, R.E. (Eds.), 1996. Implementation of solar thermal technology. MIT Press, Cambridge, MA.
Lotker, M., 1991. Barriers to Commercialization of large-scale solar electricity: Lessons learned from the Luz experience. Sandia National Laboratories, Albuquerque, NM.
Margolis, R.M., 2002. Understanding technological innovation in the electricity sector: The case of photovoltaics, Woodrow Wilson School of Public and International Affairs. Princeton University, Princeton, N.J.
Mariyappan, J., Anderson, D., 2001. Thematic review of GEF-financed solar thermal projects. Global Environment Facility, London, UK.

Notes to Appendix A

[16] Both single and multi-family dwellings were eligible for the credit, as were conservation measures installed in conjunction with a solar system; for multi-family dwellings, the 55% credit applied to systems costing less than $12,000.

[17] The Public Utility Regulatory Policies Act of 1978 (PURPA), Pub.L. No. 95-617, 92 Stat. 3117 (codified as amended in scattered sections of Titles 15, 16, 26, 42, and 43 U.S.C.A.) removed grid-related barriers to independent energy producers, known as "qualifying facilities" (QFs). PURPA created two classes of QFS: cogenerators, which "had no size (MW) limits but had to meet certain standards regarding energy utilization efficiency" and small power producers (SPPs) (Sawin, 2001, p. 106). SPPs "had restrictions regarding fuel source (generally limited to renewable or waste fuels), had a maximum size limit of 80 MW to be a QF, and a limit of 30 MW for exemption from regulation as a utility under state law as well as under PUHCA [the Public Utility Holding Company Act of 1935]. In addition to these limitations, both cogenerators and SPPs had to meet certain other restrictions such as a 50% limitation on utility ownership." (ibid.) PURPA mandated that utilities pay for power from QFs at "avoided costs," or the costs saved by not having to build new power plants, as well as sell back-up power to QFs at non-discriminatory rates. A Federal Energy Regulatory Commission (FERC) ruling in 1980 established "avoided costs" to mean a utility's full avoided costs – versus its average system costs – and required utilities to provide data on present and future costs of energy on their systems (Larson and West, 1996, p. 95). It is worth noting here that avoided costs could be calculated at the time of delivery or when a contract was signed, even if the costs based on the contract date were higher than those at the time of delivery (ibid.) The FERC ruling also required utilities to make all necessary interconnections to facilitate energy sales, and "with some exceptions, required that utilities purchase all QF electric energy and capacity regardless of the utilities' needs" (ibid.). State utility commissioners were charged with implementing the FERC rules on PURPA within one year; many states (not including California) were not generous in the computing of avoided costs under PURPA. Much of PURPA was delayed until the early 1980s because of legal issues involving state interpretations.

[18] These contracts were designed to address the delays private developers faced in negotiating purchase contracts with the utilities, which were "reluctant to agree to such contracts because of concerns about viability of projects, and concern that CPUC might not consider the contracts reasonable" (Sawin, 2001, p. 173). They were also designed to address concerns about possible under-supply, given long construction delays in the state's nuclear plants (ibid).

[19] Figures in a contemporary paper establish the percentages for the New (30%) and Emerging (10%) accounts (Wiser, 1996, pp. 470-71). The Emerging Renewables Buydown Program (renamed the Emerging Renewables Program in 2003), applied to both PV and STE technologies, among other renewable systems less than or equal to 30 kW in size. The original program helped residents and small commercial establishments by paying "50% of the system cost or $3/W (whichever is cheaper) for the installation of equipment. As prices decline, buydown payments drop to $1/W or 20% of the system's cost. Payments … continue for four years or until funds are exhausted. To qualify, … systems must primarily offset some or all of the electricity used by the consumer; be grid-connected; have a full, 5-year guarantee; and be installed by an appropriately licensed contractor" (Sawin, 2001, p. 485). "Buydown rates vary between $2000 and $3600 per kW, depending on the size of the system and the type of technology used" (EIA, 2005, p. 10).

[20]The CPUC traditionally monitored utility R&D, particularly with respect to clean energy technologies. As a result of this process, the California utilities led the industry with respect to renewable energy, including solar technologies. Indeed, "through the 1970s, utilities in California were the only ones involved in renewable energy technologies; no private producers were in the picture yet" (Sawin, 2001, p. 171). The restructuring of the electricity sector has resulted in reduced ratepayer funded R&D, as utilities have less flexibility and incentive to invest in this activity. R&D in advanced generation technologies in California dropped 85% between 1993 and 1995, while contributions from the state's investor-owned utilities to the electricity sector's R&D consortium, the Electric Power Research Institute, dropped 50% between 1994 and 1995 (Zucchet, 1995, p. 36).

[21] The Existing program offers varying financial incentives "based on the market competitiveness of California's existing renewable technologies" (PG&E, 2006). The New program offers financial incentives for the first five years of generation to eligible "projects most likely to become competitive with conventional technologies" (ibid.). The Emerging program authorized in SB 1038 offers both rebates and production incentives to customers with systems of 30 kW or less, with a particular benefit for application of renewables to affordable housing projects of an additional "25% above the standard rebate level, up to 75% of the system's installed cost" (CEC 2005, p. 3).

[22] A number of stipulations regarding funding eligibility were included in the January decision, including: (1) 10% of the funds must be used for projects for low-income residential customers; (2) energy efficiency audits will be required for existing structures to be considered for solar rebates, and new structures will need to demonstrate compliance with energy efficiency standards; (3) projects can be no larger than 5 MW, but unlike the existing SGIP program, they will be eligible for a rebate for that entire capacity; (4) the technologies eligible for incentives will include PV, STE, SWH and solar heating and air conditioning; and (5) eligible system size will be limited to 100% of historic peak load. In addition, the January decision authorized an application fee for CSI projects, which was hoped would "substantially reduce the number of unlikely projects for which administrators receive applications."

Martinot, E., 2005. Renewables 2005 Global status report. The Worldwatch Institute for the REN21 Renewable Energy Policy Network, Washington, DC.
Maycock, P.D., 2004. The World photovoltaic market. PV Energy Systems, Inc., Warrenton, VA.
Mingyuan, W., 2005. Government incentives to promote renewable energy in the United States. Temple Journal of Science Technology and EnvironmentaL Law 24, 355–366.
Mowery, D., Rosenberg, N., 1979. Influence of market demand upon innovation — critical-review of some recent empirical-studies. Research Policy 8, 102–153.
Norberg-Bohm, V., 2000. Creating incentives for environmentally enhancing technological change: lessons from 30 years of US energy technology policy. Technological Forecasting and Social Change 65, 125–148.
PG&E, 2006. Self-Generation Incentive Program. PG&E, San Francisco, CA.
Quigley, J.M., 1991. Residential energy conservation standards, subsidies, and public programs. In: Gilbert, R.J. (Ed.), Regulatory Choices: A Perspective on Developments in Energy Policy. University of California Press, Berkeley, CA.
Rader, N., Bossong, K., 1990. The power of the states: a fifty-state survey of renewable energy. Public Citizen, Critical Mass Energy Project, Washington, D.C.
Sagar, A.D., van der Zwaan, B., 2006. Technological innovation in the energy sector: R&D, deployment, and learning-by-doing. Energy Policy 34, 2601–2608.
Sanger, J.M., Epstein, P.B., 1980. Municipal Solar Utilities in California: Marketing, Financial, and Legal Issues. California Energy Commission, p. 304.
Sawin, J.L., 2001. The role of government in the development and diffusion of renewable energy technologies: Wind power in the United States, California, Denmark, and Germany, 1970–2000. Fletcher School of Law and Diplomacy, Tufts University, Medford, p. 634.
Smits, R., 2002. Innovation studies in the 21st century: Questions from a user's perspective. Technological Forecasting and Social Change 69, 861–883.
Talbot, D., Morgan, R.E., 1981. Power and light: Political strategies for the solar transition. The Pilgrim Press, New York.
Taylor, M.R., 2001. The influence of government actions on innovative activities in the development of an environmental control technology, Engineering & Public Policy. Carnegie Mellon University Pittsburgh.
Taylor, M.R., Rubin, E.S., Hounshell, D.A., 2003. The effect of government actions on technological innovation for SO_2 control. Environmental Science and Technology 37, 4527–4534.
Taylor, M.R., Rubin, E.S., Hounshell, D.A., 2005a. Control of SO_2 emissions from power plants: a case of induced technological innovation in the U.S. Technological Forecasting and Social Change 72, 697.
Taylor, M.R., Rubin, E.S., Hounshell, D.A., 2005b. Regulation as the mother of innovation: the case of SO2 control. Law and Policy 27, 31.
Taylor, M., Nemet, G., Colvin, M., Begley, L., Wadia, C., Dillavou, T., 2007. Government actions and innovation in clean energy technologies: the cases of photovoltaic cells, solar thermal electric power, and solar water heating. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2007-012.
von Hippel, E., 1976. The dominant role of users in the scientific instrument innovation process. Research Policy 5, 212–239.
Watanabe, C., 1995. Identification of the role of renewable energy: A view from Japan's challenge: The New Sunshine Program. Renewable Energy 6, 237–274.
White, I.L.J., 2006. Energy in the Public Interest. Waterloo, NE.
Wiser, R.H.,1996. Evaluating the impacts of state renewables policies on federal tax credit programs. Lawrence Berkeley National Laboratory. Berkeley, California.
Wiser, R., Pickle, S., Goldman, C., 1998. Renewable energy policy and electricity restructuring: a California case study. Energy Policy 26, 465–475.
Wiser, R., Bolinger, M., Cappers, P., Margolis, R., 2007. Analyzing historical cost trends in California's market for customer-sited photovoltaics, Progress in Photovoltaics: Research and Applications, pp. 69–85.
Zucchet, M.J., 1995. Renewable resource electricity in the changing regulatory environment, Renewable Energy Annual 1995. Energy Information Administration, Washington, D.C.